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Metals and Alloys

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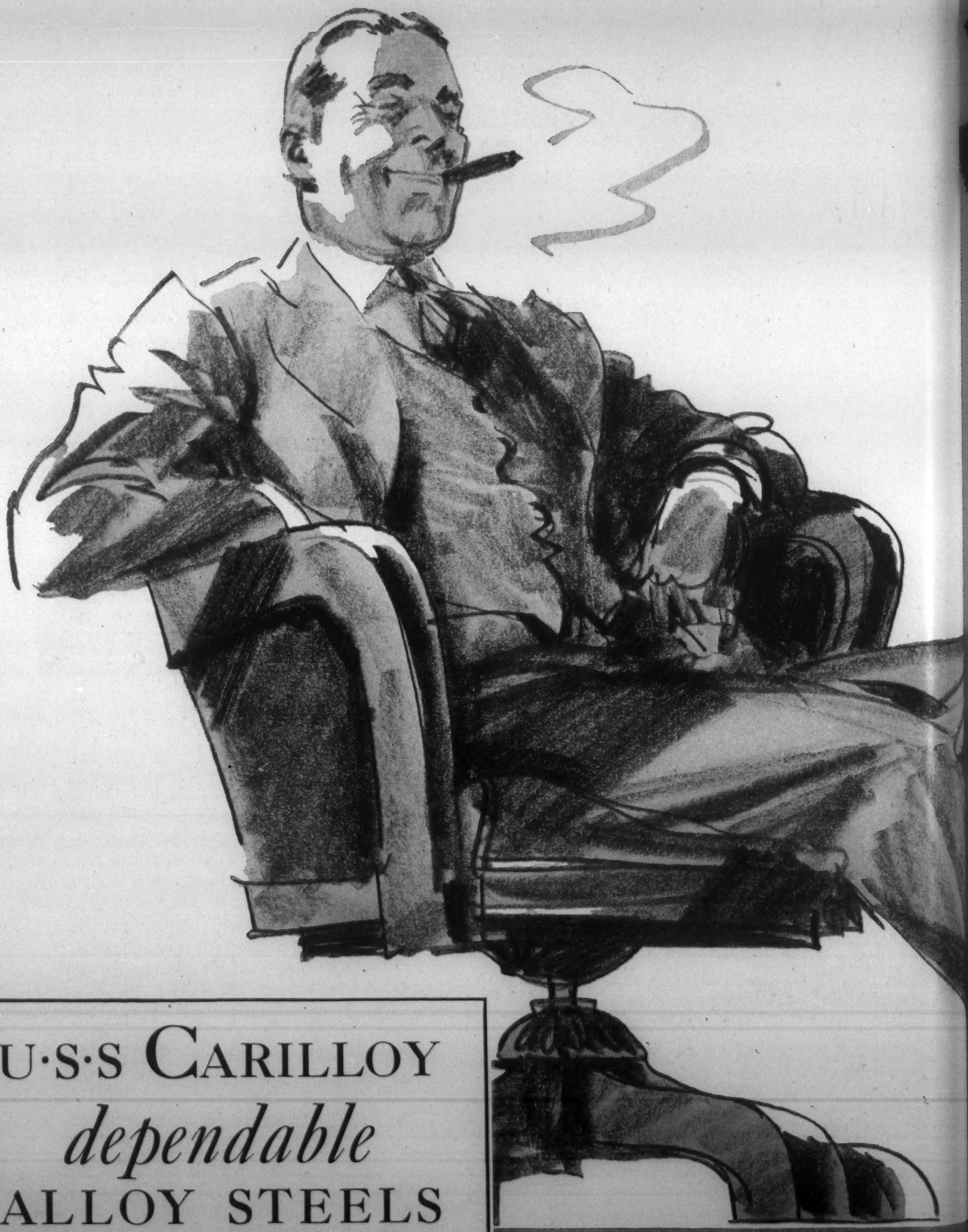
"Man at Work"...



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What Is An Alloy?

Last month we attempted to state what the word "metal" means to us. Now let's consider the question: "What is an alloy?"

An alloy is a combination of one metal with something else or several something elses. But let's confine it to binary alloys. The something else may be another metal, a non-metal, or a compound of a metal and a non-metal, *e.g.* the members of the Fe-Ni series are alloys, so are the alloys of Fe and C, or Fe_3C; and so is the Cu-CuO system, at the Cu end, an alloy. We'd prefer that the metal be in the ascendancy before we'd call the combination an alloy.

The alloying action connotes, to us, some degree of solid solubility at some temperature. (We think an alloy has to be solid, i.e. a melt isn't an alloy.) The entrance of the alloying element or compound into the metal changes its properties in a continuous manner; plotting properties against concentration, we expect smooth curves, with peaks and valleys, it is true, and often with changes of direction as we pass a phase boundary, but we don't expect cusps. Naturally, at the exact composition corresponding to a chemical compound we may call what we have, a compound instead of, or as well as, an alloy. However, what used to be thought of as definite compounds in alloys, very often turn out to span some range of composition.

Now we have to differentiate between an alloy and a mechanical mixture. If we had patience enough, we could separate a mechanical mixture into its component parts, at any temperature, by picking at it with a suitable tiny tool under a sufficiently high-powered microscope. When the mixture changes to a compound, we could no longer do this, nor could we make a mechanical separation at a temperature at which there is any solid solubility. If at another temperature the alloying component is absolutely insoluble and completely separated, it would revert to something like a mechanical mixture, but we'll take the position that, once an alloy, it's always an alloy, especially as the one time solubility has given a uniformity of dissemination of the alloying atoms or molecules that would not be readily obtainable by mechanical mixing, and so the distribution of the precipitated particles, which obviously affects the properties, is a result of prior alloying action.

We have said nothing about how the solid solubility is brought about. It may come during the cooling of the alloy after casting from the molten state, or in any other fashion. Zinc, plated upon copper, and allowed to stand at ordinary temperature, diffuses to form brass, certainly an alloy, though not having passed through the molten state. Alloy bonds between the base and a plated coating are very generally obtainable on moderate heating. A pressed mixture of metal powders in which no diffusion had taken place, can, in our estimation, hardly be termed an alloy, but after diffusion has taken place, it would be. The original mass is only a potential alloy. Some people call such a mass a "compact," but that reminds us of a powder puff. If the term gets established with its metallurgical connotation, there'll be a new dictionary definition. That's how language grows.

The case of a deposit made by simultaneous plating of two metals mutually insoluble at all temperatures in the solid state would be a border line case, because the atoms would be so intimately distributed that even infinite patience and an impossibly high powered microscope wouldn't allow us to pick them apart. One can conceive of other methods of making intimate mixtures, such as the sucking up of one metal into the pores of a sintered powder "compact" of another metal. If we filled these pores with an organic plastic, no one would call it an alloy. With a metal filling, at a temperature below that of solubility and diffusion, the effect is mechanical only; no forces save those of positioning come into play. Raise the temperature so that diffusion, i.e. some degree of solubility, occurs, and alloying starts, the object then becomes an alloy. Yet, one might find a degree of adhesion between pore and undiffused filling that goes beyond mere mechanical positioning. Lead, reduced by aluminum from a fused lead salt onto the solid aluminum surface, adheres with a force that one might call alloying, although it is usually thought that lead and aluminum have no mutual solid solubility. However, whether or not one can detect it by the means at our disposal, some degree of mutual solubility even in the solid state probably exists for practically any pair of solids. At any rate, should one wish to make that assumption, it is awfully hard for the other fellow to disprove it.

One difficulty crops up in the case of a metal and

(Continued on page 65)

by EDWIN F. CONE

A K-3B Fairchild Camera Being Used for Oblique Photographs.

Metals and Alloys in Aerial Cameras

Photograph of Greater New York Area Made from an Altitude of 26,300 ft. with a Fairchild Camera.
(Official photograph of the U.S. Army Air Corps.)

This article is another in a series on the general subject of The Metallurgical Needs of the Non-Metallurgical Industries. There are many manufacturing operations which, while they are essentially non-metallurgical, do make more or less extensive use of metals and alloys. In some cases this involves the use of many alloys or metals, complicated as to composition and properties and involving no little expense—they are essential, for the process would not function without them. This article deals with aerial cameras—the metals and alloys used in their construction.

The articles of this general nature which METALS AND ALLOYS *has thus far published are listed at the end of this discussion.*

IN THE INDUSTRIAL WORLD as well as in military and other operations, the taking of pictures from the air has assumed large proportions. The aerial camera of today has become a highly important piece of equipment. And the role it is playing is rapidly expanding. Its development and use have, of course, been made possible by the strides that have been made in the conquering of the air by man.

To many it will appear at first thought that the use of metals or alloys in the building of an aerial camera is negligible or at least of quite minor importance. But decidedly this is not so. Through the courtesy of the Fairchild Aerial Camera Co., Jamaica, N. Y., it has been demonstrated to the writer—to his surprise—that many kinds of metals and alloys enter into the manufacture of these cameras and that their perfection and reliability could only be possible by the use of such materials. With the exception of the lens the Fairchild aerial camera consists entirely of metals or alloys. It is the object of this article to delineate, not in too much detail, how these metals are used in building an aerial camera.

It should perhaps be said first that metals and alloys are used in these cameras for two main reasons: The cameras must be light, and they must possess rigidity and permanence. They could be made of wood for lightness but the necessary rigidity would be missing. Rigidity is required so as to maintain the high initial accuracy built into the camera. Then, too, they must be resistant to shock and vibration or the resulting picture would lack the clearness and sharpness in detail otherwise obtained.

Types of Aerial Cameras

There are several different types of aerial cameras made by the Fairchild company, depending on the work to be done. There are single-lens cameras, of which there are several types—the general purpose type, the special purpose and the high precision mapping or photogrammetric cameras, as well as multi-lens mapping and machine gun cameras—all using many different metals and alloys.

The general utility camera—the K-15—serves a multiplicity of purposes and needs—general industrial airviews, aerial mapping photography, pictures of cities and so on—usually from heights of 1,000 to 25,000 ft., depending on the particular application. General air views (oblique photography) for example may be taken from altitudes as low as 500 ft. under special conditions, but these are usually taken at about 1,000 to 2,000 ft. For mapping purposes, the lowest practical operating altitude is 5,000 ft. because at lower altitudes the air is rough and bumpy. Most large mapping projects are flown at 10,000 to 25,000 ft.

The special purpose camera—the K-7C—described here, on the other hand, takes views from heights of up to 30,000 ft., usually for military purposes—views which take in a wider area than the general utility type and provide large image size and sharp definition of detail.

The range of cameras covers a small hand-held camera for oblique photography only up to multi-lens cameras used exclusively for mapping purposes. The small hand-held type sells for about $400 with the price range from this figure up to $28,000 each.

In this article—in order to provide a general idea of the metals and alloys used—only the general purpose and one of the special purpose types are discussed.

THE GENERAL PURPOSE AERIAL CAMERA

There are four main parts to a Fairchild general utility or general purpose aerial camera, designated by the company as K-15:

1. The Roll Film Magazine
2. The Camera Body
3. The Lens Cone
4. The Lens and Shutter Assembly

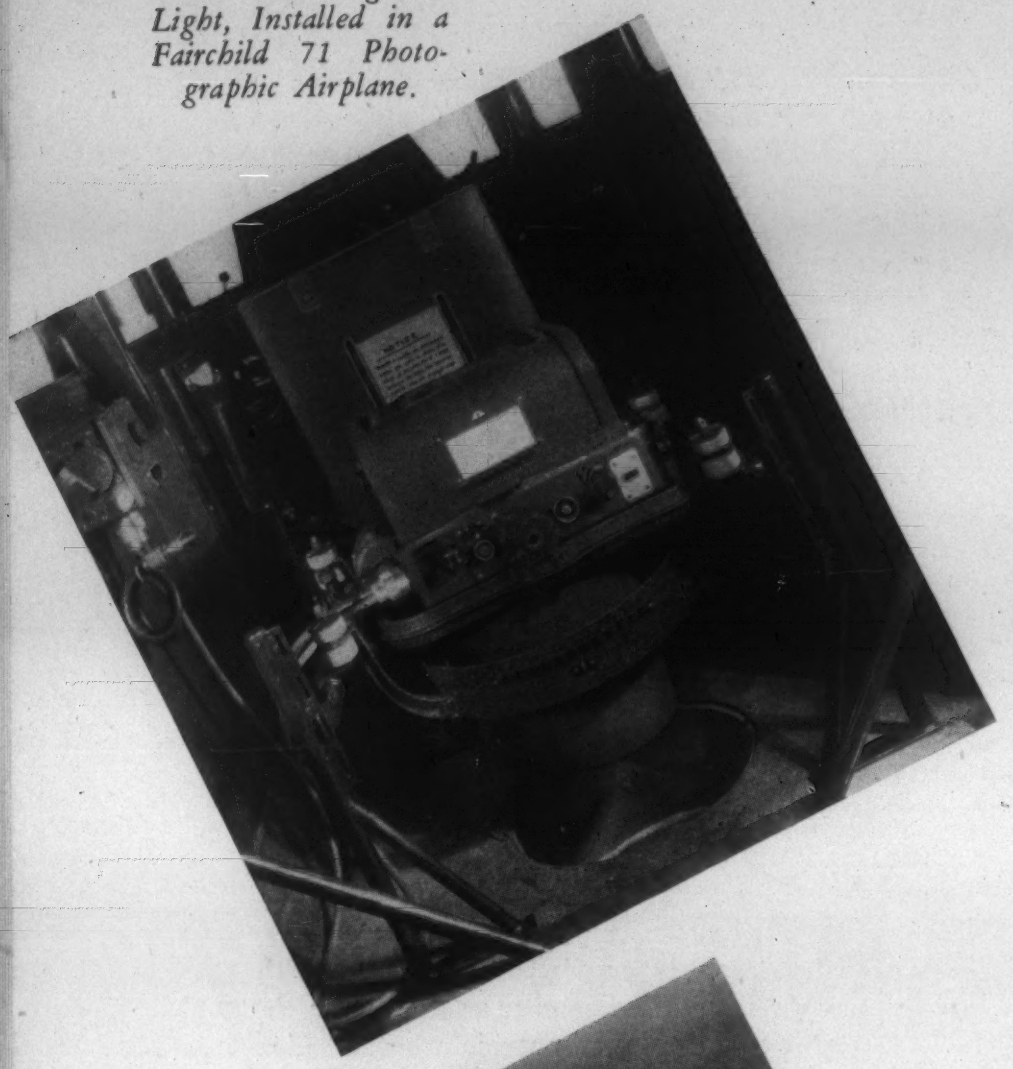
All these parts are made mainly of metals and alloys with the shutter predominant as to number and variety involved. Accompanying illustrations show these four parts disassembled.

Naturally, in order to secure lightness, commensurate with strength, rigidity and proper balance, aluminum or magnesium is an essential metal. In the general purpose camera, aluminum predominates. The four parts will be discussed in order.

1. Metals in the Roll Film Magazine

The magazine, or top section of the camera, which contains the photographic film, is made of three main parts: The two side frames, the base frame or plate, and the cover which is removable.

Fairchild K-3B Camera, with Mount, Cables and Signal Light, Installed in a Fairchild 71 Photographic Airplane.



The side plates are die castings of an aluminum alloy. Each is 3/32 in. thick, an unusually difficult section to die cast. The aluminum alloy used is a 12 per cent Si alloy, balance mainly Al. Its properties are about as follows, as die cast:

Tensile strength	33,000 lbs. per sq. in.
Yield point	14,000 lbs. per eq. in.
Elong. in 2 in.	2.0 per cent
Impact	2.5 ft.-lbs.
Brinell	80.0
Weight	0.095 lbs. per cu. in.
Melting point	1,050 deg. F.

Most of the die castings used by Fairchild are made by Doehler Die Casting Co., Batavia, N. Y.

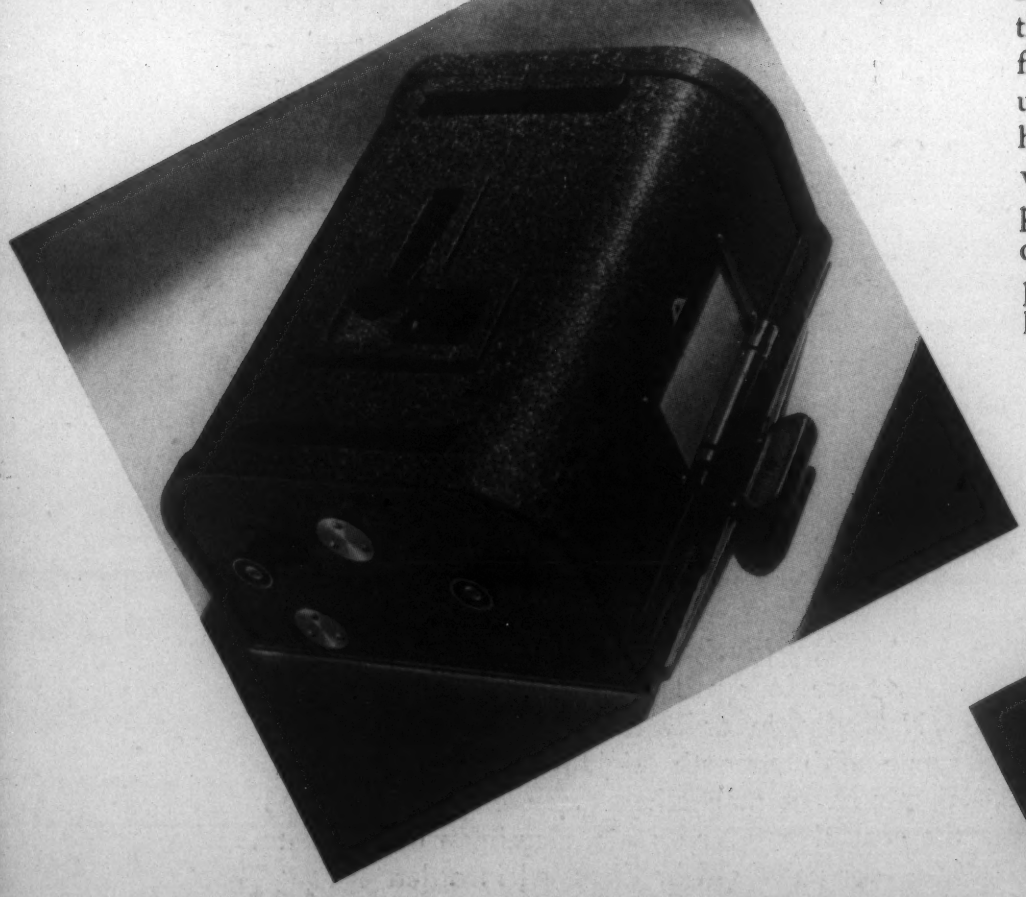
The base frame or plate, on which the two side frames rest, is also a die casting of the same aluminum alloy.

The cover of the roll film magazine is made of sheet aluminum alloy—17ST—of the following composition:

	Per Cent
Copper	2.50
Magnesium	0.30
Aluminum	Balance

Its thickness is 3/32 in. and it is formed to shape.

In the magazine is the mechanism which regulates the rolling of the film, known as the magazine drive. This drive advances fresh film for each exposure, regulates the film-spacing mechanism, and operates the mechanical pressure plate which holds the film flat at the instant of exposure, when this feature is used in the magazine. There is another method for holding the film flat—by means of a vacuum plate which draws or sucks the film firmly in the focal plane. In the first case—the pressure plate is a sheet of aluminum alloy, 17ST. In the other, the vacuum plate is a sand casting of aluminum alloy No. 108, heat-treated, and machined absolutely flat.



(Above) A Unit 30 Roll Film Magazine for a K-3B Camera.

(Right) The Drive Unit of 30 Roll Film Magazine which Advances the Right Amount of Film for Each Exposure.

The magazine is made up of many different parts —gears, housings, shafts, etc.—into which are incorporated the following metals and alloys:

Stainless steel (18 & 8)
Beryllium copper
Aluminum castings
Duralumin parts from sheet or bar stock
Cr-V tool steel

The gears are made of SAE 6150 or 6170 steel, Cr-V, heat-treated according to standard practice.

The driving mechanism for the magazine is operated by the main driving mechanism in the camera body, described later. When the camera case drive is wound, manually or electrically, a single operation winds the shutter (puts tension on the shutter spring), advances the film in the magazine, and releases the pressure plate if used.

2. Metals in the Camera Body

The camera body is the middle portion of the general utility aerial camera. On it rests the roll film magazine which houses the driving power for the film. In it is placed the driving mechanism which drives the mechanism in the roll film magazine and the apparatus which controls the shutter (in the cone). As can be seen from one of the illustrations, it is mainly one frame or casting, made in sand molds. Here again aluminum predominates, the alloy used being No. 108 of the following composition:

	Per Cent
Copper	4.00
Silicon	3.00
Aluminum	Balance

These castings, purchased from a reliable foundry, are heat-treated before and during the various steps in machining to secure freedom from strain and creep. The average thickness of these castings is 1/8 in. and the average weight is 2 lbs.

Both plane surfaces of the camera body, as well as the under surface of the magazine, are accurately machined in a large machine shop in the company's plant. The fit must be close and perfect—to maintain the optical alignment to the mechanism and to shut out light.

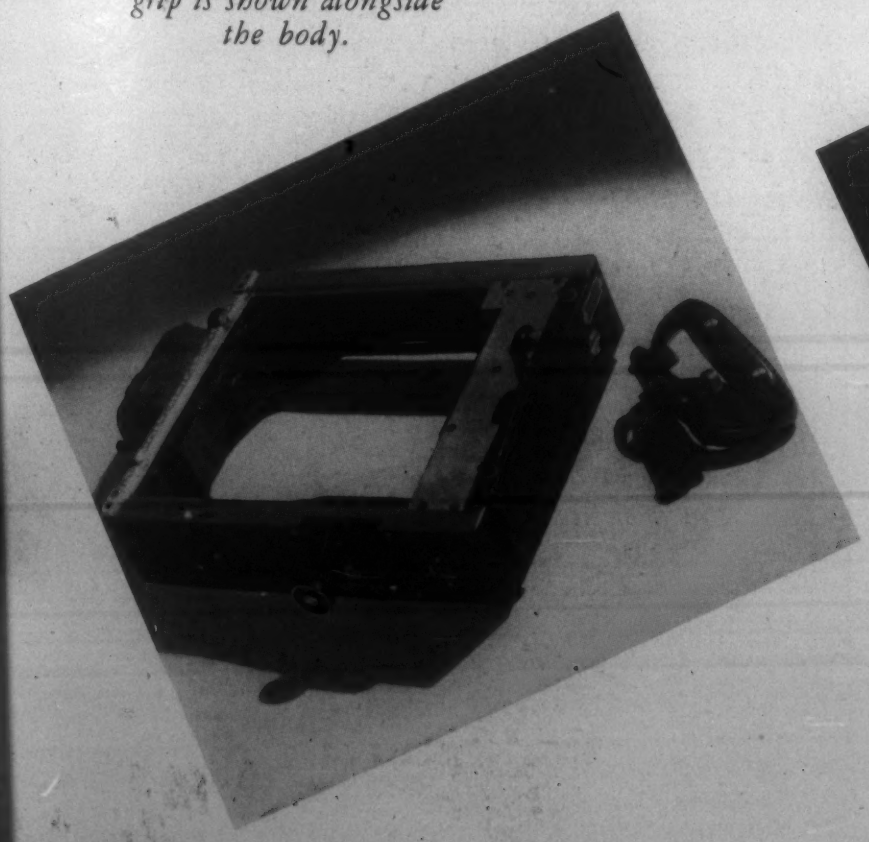
3. Metals in the Lens Cone

In the general purpose cameras the lens cone is quite different in composition and construction from the one in the special purpose type, to be described later. In the general camera, the cylindrical part of the lens cone is spun from an aluminum alloy—same material as in the cover of the magazine. In addition to this there are two castings which fit inside of the cone—one, the plate at the top which is attached to the under side of the camera body, and the other the casting which is located near the lower end of the lens cone and which holds the lens and shutter assembly. These castings are made of aluminum alloy No. 108, already described above. They are also heat-treated as already indicated. The thickness of the spun portion of the cone is only 3/32 in. Both castings are accurately machined to fill their appointed function. The weight of the assembled cone, complete with lens and shutter, varies from 13 lbs. to 31 lbs., depending on the size or length of the cone. The weight of the K-15 cones, less the lens, varies from 10 to 25 lbs. The lens and shutter assembly alone may weigh from 2 to 6 lbs.

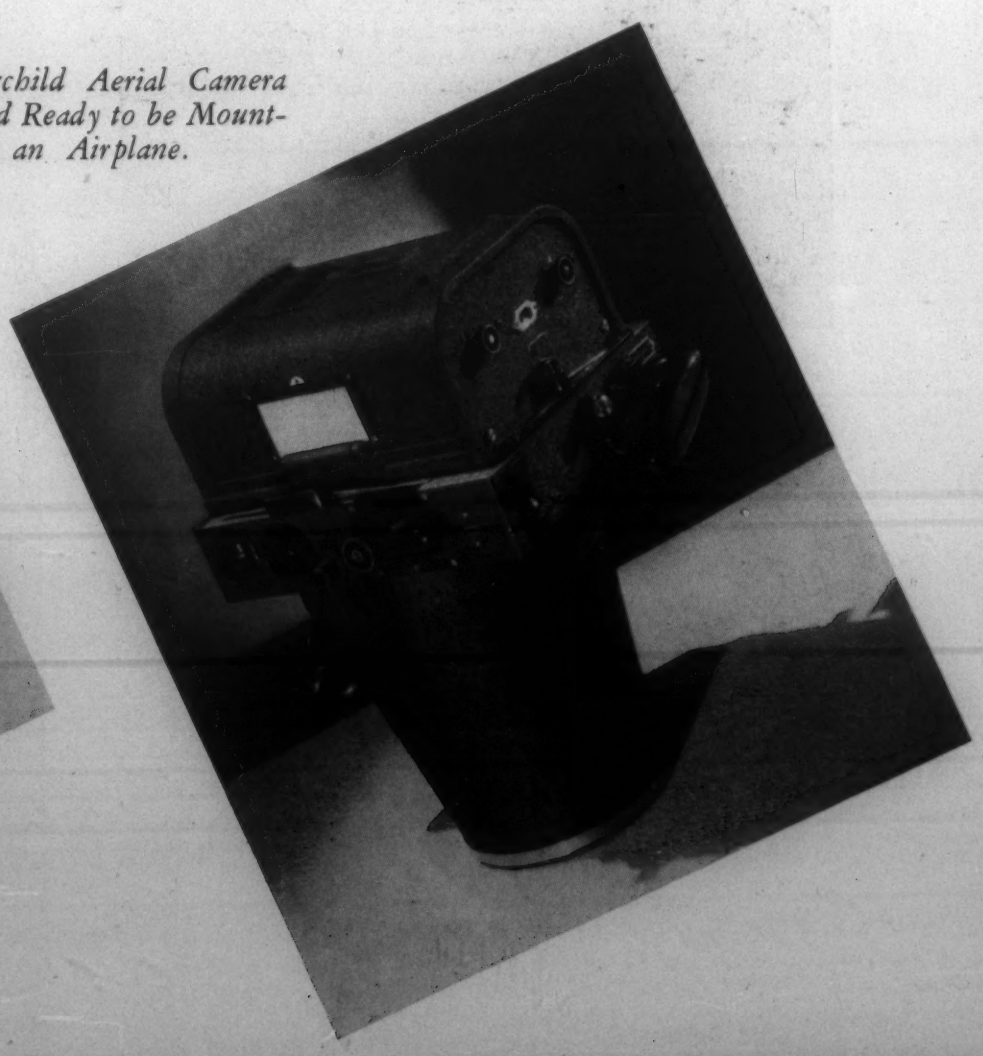
4. Metals in the Lens and Shutter Assembly

The illustration of the lens and shutter assembly should be consulted to understand more clearly how

A K-3B Camera Body. The detachable handgrip is shown alongside the body.



A K-3B Fairchild Aerial Camera Assembled and Ready to be Mounted in an Airplane.



metals and alloys are used in its construction. For reasons of policy only a brief description is possible.

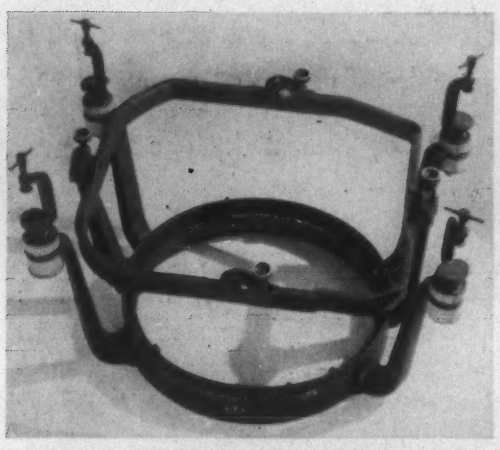
There are two main ribbed plates in the casing of the shutter. These are sand castings made of aluminum alloy No. 108. These castings are heat-treated same as the castings for the frame of the case. The leaves which operate to open and close the shutter are of thin plates of a special blued spring tool steel. The two main plates are fastened together with bolts and, in the space between the plates, the leaves of the shutter operate. The lenses, which vary in size according to focal length and aperture, are held in the shutter by means of a barrel of a bronze casting, 84 to 86 per cent Cu and 4 to 6 per cent each of Sn, Zn and Pb.

There is also found in the shutter assembly the elaborate and delicate mechanism which operates the leaves of the shutter and other parts and which is controlled by the central mechanical apparatus in the camera body. So much depends on the efficiency of this part of the camera that the materials in it must be of the best quality. Some of these which enter into this operating mechanism are as follows:

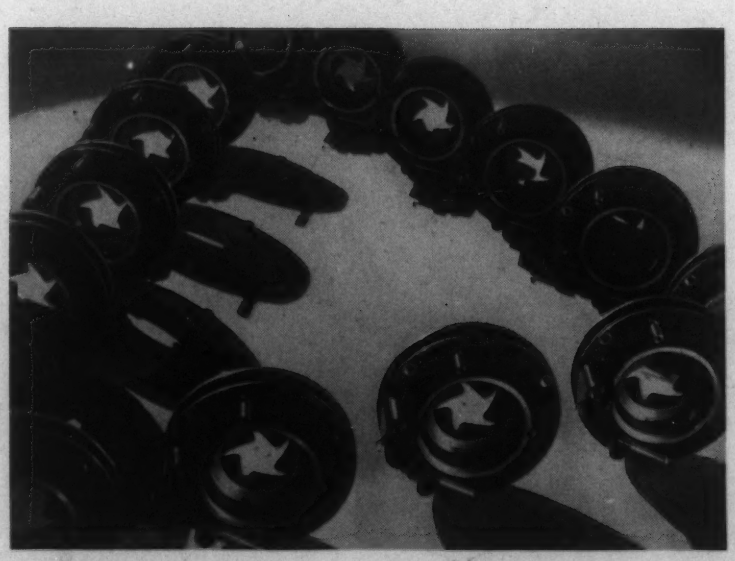
Cr-V steel—SAE 6150 and 6170	Gears and Cams
Swedish tool steel	Springs
Blued spring tool steel	Leaves
Beryllium copper (heat-treated)	Springs
Brown and Sharpe tool steel	
Bronze castings	
Stainless steel (18 & 8)	Screws, etc.

One of the illustrations shows the mount on which the camera is supported. This is made in three parts of sand cast aluminum alloy No. 108, heat-treated. Besides these main parts, there are also involved in the completed assembly: Stainless steel, duralumin and sand cast bronze castings.

It will be noticed that, in the illustration which shows a Fairchild aerial camera in position in an airplane, there are two upright supports on which



A Vertical Suspension Mount for a K-3B Aerial Camera.



Interchangeability of Parts and of Units is Assured by Elaborate Tools. A group of Fairchild lens shutter assemblies, each exactly alike with complete interchangeability of the finished units and of component parts.

(Right) The Exacting Cold Chamber Test. All Fairchild cameras are subjected to low temperature tests.

Alaskan Mapping Expedition Photographs 13,000 Sq. Mi. of Terrain with a Fairchild camera.
(Courtesy: Bureau of Aeronautics, U. S. Navy)

the mounting of the camera, just described, rests. These, which are a part of the airplane, are made of Cr-Mo welded steel tubing.

The weight of the average general utility camera ranges from 35 to 40 lbs. and those, with a cone longer than usual, weigh from 40 to 60 lbs. each.

THE SPECIAL PURPOSE AERIAL CAMERA

The special purpose Fairchild aerial camera, described here—the K-7C—uses a lens of 24 in. focal length and takes a picture 9 by 18 in. in size. It provides wide area coverage with large image size and sharp definition of detail from high altitudes. It is used principally for military reconnaissance.

The construction is similar, as are also the metals and alloys used, to the general utility type. There are however but three main parts: The roll film magazine, the camera body and lens cone in one piece; and the lens and shutter assembly.

1. The Roll Film Magazine

In this camera where lightness for transportation to great heights is a factor, the predominant metal is magnesium. The frame or side plates are made of magnesium alloy sand castings—usually Dowmetal or Bohnalite X5. The cover is of aluminum alloy sheet, 17ST, as in the other camera. The drive mechanism in the magazine is also practically the same as in the other camera as to metals and alloys incorporated. For closing the bottom of all removable magazines there is provided a stainless steel (18 & 8) sheet, 0.032 in. thick, which acts as a light slide.

2. The Camera Body and Lens Cone

In the general purpose camera these were separate parts—in this special purpose type they are virtually one. The length of the combined parts—there being really four pieces or parts—is somewhat greater than in the average general purpose camera.

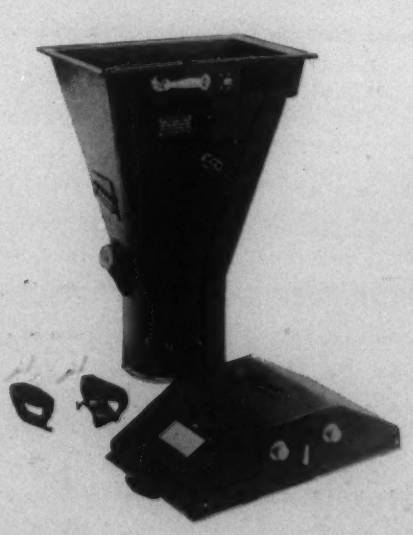
The main part of the body and cone is a shell which is made of aluminum alloy (17ST) sheet, 3/32 in. thick, formed and not spun into the desired shape—a shell which contains in its upper part the body casting, in its lower portion the lens and shutter assembly, and to the lower end of which is attached the prolongation of the cone. The cone of this particular type (K-7C) is designed in this manner to reduce weight and bulk.

The body part of this portion of the camera is an aluminum alloy casting made of alloy No. 108 similar to the body in the other camera, heat-treated. It serves also to stiffen the upper part of the thin shell. The drive mechanism in this part is the same as in the body of the general purpose camera—as to metals and alloys involved. The outer shell is used principally to streamline the camera. If the entire cone and body were made as a single casting, weight and bulk would be excessive.

There was mentioned above the lower end of the cone which is attached to the main part of the cone,

Testing a Fairchild Shutter for Accuracy of Speed and Efficiency, Using a Special Shutter Testing Machine Developed by the Company for Carrying Out Exacting Tests.

Lens and Shutter Assemblies Complete with the Lenses.



The Two Main Parts of the Fairchild Special Purpose Camera —the K-7C.

The K-7C Camera Assembled and Ready to be Installed in an Airplane.

formed from aluminum sheet. This is a sand casting of magnesium alloy—Dowmetal or Bohnalite—not heat-treated. It is riveted to the shell of the cone by means of copper rivets.

The fourth part of this combined body and cone is a sand casting of aluminum alloy No. 108 which fits on the inside of the prolongation of the cone and in which is placed the lens and shutter assembly mechanism.

3. The Lens and Shutter Assembly

This lens and shutter assembly is approximately the same as that used in the general purpose Fairchild camera—the same as to the many metals and alloys employed.

GENERAL REMARKS

It should be emphasized that in selecting the metals and alloys to be incorporated in such delicate, highly sensitive and expensive products as are these aerial cameras, not only the best of materials must be considered but those that will withstand the most unusual conditions of coefficient of expansion; stress; weather; variations in temperature, sudden and severe. At the same time the accuracy and the efficiency of the camera must be maintained and assured.

In this connection it is of decided interest to record that the Fairchild company maintains equipment with which it tests its cameras as to working efficiency at temperatures as low as minus 50 deg. F. The company is proud to show a radiogram from the Second Byrd Antarctic Expedition at Little America testifying to the satisfactory operation of a Fairchild aerial camera at minus 65 deg. F. Among other tests may be mentioned the shutter and the lens tests.

It may be added that, at the Jamaica plant of the Fairchild company, complete equipment is in operation for electroplating various parts with silver, copper, nickel or cadmium.

The company also maintains equipment for heat treating some of the parts and tools. This consists of electric furnaces, salt baths, gas furnaces and so on. An extensive machine shop is also necessary for accurately finishing the various parts of the cameras which must fit with extreme precision.

Because absence of light is an essential and because the bare metals and alloys are bright, the inside of the camera must be finished black. An optical black lacquer is used for this. The outside of the cameras is finished with a crinkle black lacquer sprayed and baked.

Recapitulating, the various metals and alloys which are used in the various parts of these two types of Fairchild aerial cameras are as follows:

Aluminum alloy Alcoa No. 108, as sand castings
Aluminum alloy Alcoa No. 13, as die castings
Aluminum alloy 17ST
Magnesium alloy—Dowmetal, as sand castings
Magnesium alloy—Bohnalite X 5, as sand castings
Stainless steel—18 & 8
Beryllium-copper castings—2½% Be
Beryllium-copper wrought material—2½% Be
Cr-V steel
Duralumin
Swedish tool steel
Bronze castings
Brass parts
Blued spring tool steel
Copper rivets
Cr-Mo tubing
Brown & Sharpe tool steel
Cu, Ag, Ni and Cd as plating

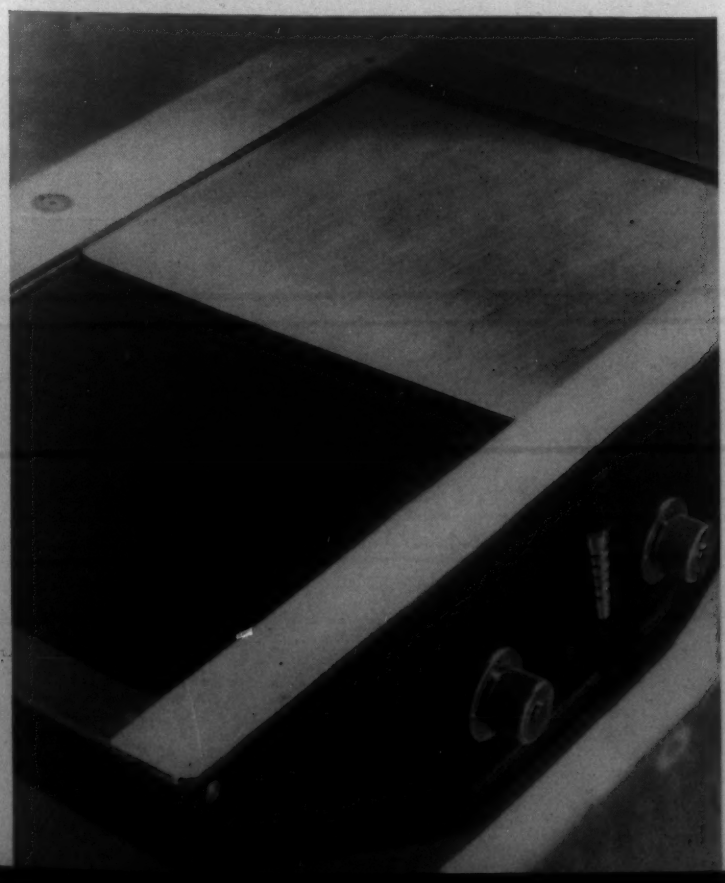
These various metals and alloys are found as:

Sheets, plates, shafts, die castings, sand castings, screws, bolts and nuts, rivets, spun and formed shapes and other parts.

This recital reveals in general the vital role which metals and alloys play in the production of this highly important equipment, used in peace or war. Other types of cameras, made by the Fairchild company—such as the machine gun camera, the precision camera, the five lens camera and so on—involve the application of the metals and alloys already discussed. In some stainless steel is the main constituent.

Thus, because of the results of research in developing alloys and of heat-treatment technique, these complicated instruments of high precision and efficiency have been made possible.

Apparatus for Holding the Film Flat. A vacuum in plate draws or sucks the film firmly in the focal plane.



Related Articles in Metals and Alloys

"Special Metals in Oil Field Practice." P. H. Brace. Vol. 5, Sept., 1934, page 181.

"Metals and Alloys in Dentistry." O. E. Harder. Vol. 5, Nov., 1934, page 236.

"Metals and Alloys in the Pulp and Paper Industry." J. D. Miller. Vol. 5, Dec., 1934, page 263.

"Some Metallurgical Aspects of the Radio Tube Industry." Stanton Umbreit. Vol. 6, Oct., 1935, page 273.

"Metallurgical Needs of the Glass Industry." R. D. Smith. Vol. 7, Sept., 1936, page 217; Oct., page 263.

"Metals and Alloys in the Printing Industry." B. W. Gonser and S. Epstein. Vol. 8, Jan., 1937. page 3; Feb., page 59; Mar., page 63; April, page 117.

ENGINEERING USES OF

Heavy Nickel Electrodeposits

AND OTHER PLATING ADVANCES

"Nothing is impossible to diligence and skill" is an epigram ideally exemplified in recent progress in nickel electroplating. Not so long ago the production of pore-free thin electrodeposits was something to dream about after the kiddies had been sent to bed, and it was outright heresy to believe that electroplated coatings could have useful engineering properties, i.e. *could be anything but hard, brittle surfaces suitable only for appearance effects or corrosion protection.*

Advances in plating technique have now brought these erstwhile "impossibilities" into the realm of established fact, as this digest of several recent articles demonstrates. Almost any plating shop may now produce electrodeposited nickel in a range of physical properties somewhat higher than are ordinarily found in rolled or cast nickel and over a broader range than is customary with the usual furnace and mechanical treatments.—The Editors.

by FRED P. PETERS

Assistant Editor, METALS AND ALLOYS

DURING THE LAST TWO YEARS the art of electroplating has advanced at an ever-accelerating pace. Refinements in the process have brought improved appearance and physical properties; modernization and the use of continuous lay-outs have lowered costs; research has resulted in new types of deposits of single metals or alloys. With all of these the professional electroplater and the electrochemist interested in plating are quite familiar. The engineer, however, accustomed as he is to thinking of electrodeposition as a chemical operation for finishing purposes only, may be surprised to know that the potentially most valuable developments of the last few years are of most interest to *him,* for electroplating has entered the field of shape-making processes and electroplated coatings have become metals with engineering properties on a par with those of materials produced by the usual casting and mechanical operations.

The mechanical properties of nickel electrodeposits have always been regarded with some suspicion, although it has been evident that coherent, strong deposits are possible of attainment. A number of articles[1,3,4] have appeared that give physical properties of deposits and show that they are ductile and strong when made under certain controlled conditions. In a very recent paper Wesley[5] has gone much farther in presenting a simple series of baths and operating conditions that permit the production of electrodeposited nickel over a controlled range of mechanical properties so broad as to fill completely the gap in hardness between copper and electrodeposited chromium. His paper also shows the extent to which such "electrolytic casting" to form or build-up parts or surface metal for engineering uses can be applied in industry.

It has also been commonly reported and believed in many quarters that electrodeposits necessarily have a more porous structure than other forms of metal, but the feeling has steadily grown that the prevention of porosity in electrodeposits is just as possible as the production of dense cast or rolled products. In an earlier article in METALS AND ALLOYS[1] data taken from various sources were given to show that nickel deposits need not be more porous than other forms of metal. More recently, Hothersall and Hammond[2] have made a thorough study of the causes of porosity in nickel deposits, and by applying cures were able to produce deposits of barely measurable thinness that had no detectable pores. Their work—which, unlike Wesley's, has yet to be applied in practice—is described more fully in later paragraphs.

Control of Properties of Deposits

To be suitable for industrial use, the metals of interest to the engineer must have certain definite, useful and controllable qualities. Electrodeposits have not been considered as meeting such engineering

requirements, chiefly because of their traditional brittleness and "characteristic" porosity. The excellent specific gravity and mechanical property values obtained by Wesley[5], however, indicate that the nickel deposited in his process can hardly be of a porous nature, and—vastly more important from the engineering viewpoint—can compare favorably as to hardness, strength and ductility with other materials.

Wesley views electrodeposition as a cold process that, although it has its own peculiar but avoidable defects, does not introduce the ill effects of heating, such as "weld decay," cracking under thermal stress, softening with loss of strength, or hardening with loss of ductility. The principal point of difference between electrodeposits employed for appearance uses and those for engineering applications is in the thickness and probably the grain size. The familiar "appearance" nickel plate is 0.001-0.002 in. thick. 0.005 in. may be applied for resistance to corrosion and wear, while deposits of the order of 0.02 in. are used for reclaiming mismachined parts. "Cold castings" as thick as 0.2 in. have been applied in building up large worn shafts and in forming completely electrodeposited metal objects, such as sheets and screens.

In Fig. 1 are shown the ranges of hardness that have been reported for thick deposits of metals, as given by Hothersall.[9] The intermediate but very broad range covered by nickel deposits is evident. In this country the production of heavy chromium deposits of high hardness and thick enough to be ground to exact dimensions where necessary has become commonplace. In Europe, however, the salvaging of worn parts by the electrodeposition of other metals (chiefly iron) has developed gradually towards the use of nickel as the depositing material because of its controllable deposition and its physical properties, which include ductility and machinability not possessed by the harder chromium deposits.

Wesley shows that for practical purposes the complete range of physical properties in plated materials for engineering applications can be supplied by equipping the plating shop with only 4 baths, three of which are already present in almost every shop. These are listed in Table I; the hard nickel bath is the only one not in common use today.

Table I.—Four-Bath Electroforming Shop

Bath	Vickers Hardness
Copper: Acid Bath	40-60
Soft Nickel: Watts Bath	130-200
Hard Nickel	250-450
Chromium	500-900

The hard nickel bath is a simple modification of the well-known double salts or nickel ammonium sulphate bath; the most promising composition is:

Nickel sulphate (crystals)	16 oz. per gal.
Ammonium chloride	2.3 oz. per gal.
Potassium chloride	1.1 oz. per gal.

The temperature is 120-130 deg. F.; pH is 5.2-5.8 and current density 20-50 amps. per sq. ft. according to the use of agitation. Control of hardness in this and in the Watts type soft nickel bath is achieved by controlling the temperature and current density. Generally, for a given bath, higher temperatures result in softer plates, and high current densities in harder plates. The details of control are outlined by Wesley in his paper and are covered fully in a set of instructions issued by the International Nickel Co., Inc.

Comparison with Other Forms of Metal

The mechanical properties of the heavy coatings as determined by Wesley are within ranges comparable to those of the steel machine parts on which the nickel would be deposited. Table II gives a comparison of these property values with those of wrought and cast nickel.

Fig. 1. Ranges of Hardness of Electrodeposited Metals, as Reported by Hothersall.[9]

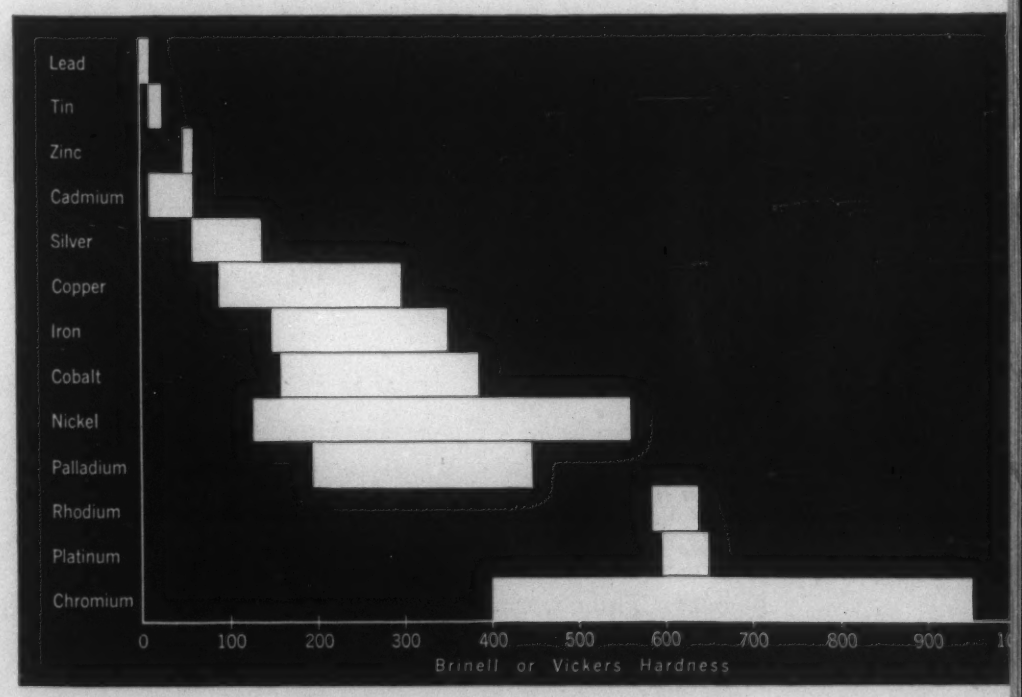


Table II.—Comparison of Mechanical Properties of Heavy Electrodeposited Nickel with those of Rolled and Cast Nickel

Form	Hardness V—Vickers B—Brinell	Tensile Strength lbs./in.²	Elongation % in 2 in.	Density at 23°C. g./cc.
Cold Rolled, Annealed	100-130(B)	65-75,000	45-50	8.86
Cold Rolled, Hard	180-230(B)	90-105,000	15-30	...
Castings	80-125(B)	55-70,000	15-30	...
Soft Electrodeposited	150(V)	51,000	28	8.86
Medium Electrodeposited	230(V)	98,000	21	8.91
Hard Electrodeposited.	360(V)	132,000	1	8.89

Gardam and MacNaughtan[10] report similar data for electrodeposited Ni plated at lower temperatures and lower current densities. They succeeded in producing deposited nickel with an elongation of 37 per cent (in 1 in.) with baths in the pH range of 4-5.5.

It will be seen that the values for the electrodeposits indicate that they are metallurgically sound

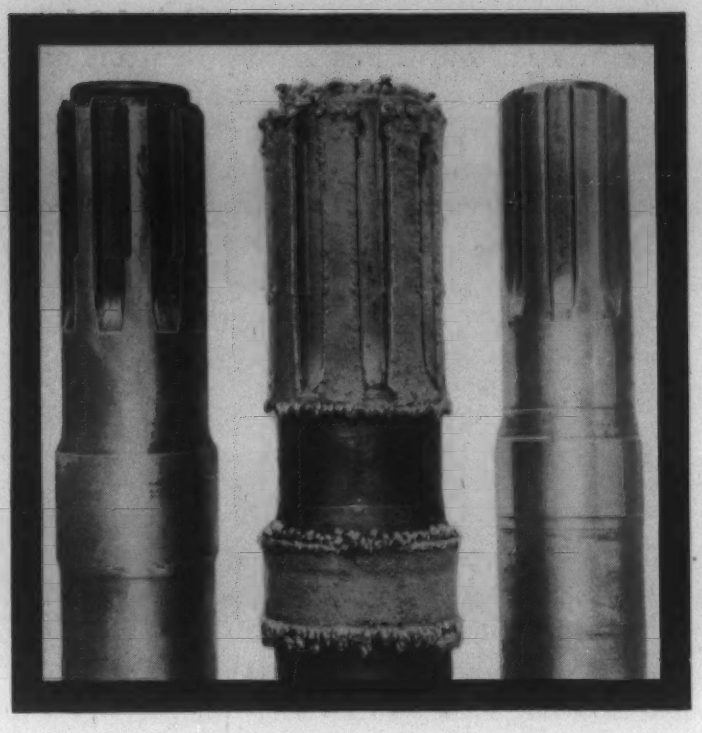


Fig. 2. Repair of Worn Spline Shafts as Done by Fescol, Ltd. At left, the worn shaft; in center, the as-deposited shaft; and at right, the deposited shaft after finish-machining. From Bonilla.[11]

and that the process of making them can properly be called "cold casting." The hardest deposits (*i.e.* those over 400 Vickers) show a tendency to form laminations and develop cracks. Where such hardnesses are required in very thick deposits, a better product is usually obtained by building-up with tough nickel of moderate hardness and finishing with hard nickel or chromium.

Engineering Uses—Electroforming

The uses of heavy nickel deposits, according to Wesley, depend on the good mechanical properties just described, plus resistance to wear or corrosion or both. The more important uses are for (1) electroforming, *i.e.* the manufacture or reproduction of articles by electrodeposition, and (2) building-up or surfacing, in which the deposit becomes a part of the object upon which it is "electrocast."

Familiar examples of the production of useful articles by electrodeposition (electroforming) are electrotyping, reproduction of phonograph master and stamping plates and, more recently, the manufacture of electroformed sheet, tubes and screens. The plating problems involved in the production of electrotypes are outlined by Wesley, and have been more fully discussed in an earlier article by Gonser and Epstein.[12] For ordinary work, electrotypes are made of copper, with nickel used only as a thin coating. For special work, such as that at the Bureau of Printing and Engraving, heavy nickel deposits are used. According to Gonser and Epstein, the number of impressions obtainable with different kinds of electrotypes have been reported as in Table III.

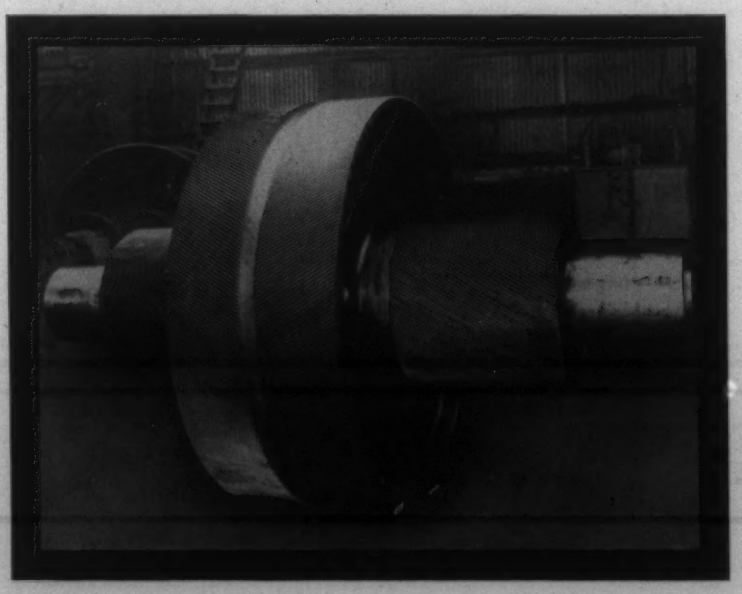
Table III—Number of Impressions Obtainable with Various Electrotypes.

Kind of Electrotype	Average Life of Plate, Impressions
Flat copper, from type-form	150,000
Flat nickel, from type-form	600,000
Flat copper, from half-tone	100,000
Flat nickel, from half-tone	300,000
Curved copper, from type-form	300,000
Curved nickel, from type-form	1,000,000
Curved copper, from half-tone	200,000
Curved nickel, from half-tone	800,000
Chromium plating over copper or nickel will double the above.	
Original zinc etching	30,000
Original copper half-tone	50,000

Electroformed copper tubes have been made commercially and electroformed copper sheet is available in this country in light gages where the price of the rolled product is relatively high on a pound basis. A commercially practiced method of making electrosheet copper, and the uses of the product, have recently been described by O'Brien.[13] Wesley, in his paper, discusses a bi-metal copper-nickel sheet made electrolytically (in England), which can be deep-drawn from 0.031 in. composite sheet to give a 7-in. kitchen saucepan with the copper layer on the outside and the nickel on the inside. This illustrates how high the metallurgical quality of electroformed sheet can be made without the benefit of forging or rolling treatments. The production of nickel sheet by electrodeposition has been described by Wynne-Williams.[14]

An outstanding new application of electroforming is the manufacture of screens by direct deposition of copper or nickel in thicknesses suitable for industrial use. The advantages of this method of screen-making are cited by Wesley as high accuracy in opening-size, flexibility in choice of relative area of metal and openings, and better resistance to wear and fatigue because of elimination of wire knuckles.

Fig. 3. Second-Reduction Turbine Gear after Repair of Shafts. The shafts, each 11 ft. long and 8½ tons in weight, were repaired by Fescol in 20 days, whereas several months would have been required to get new shafts.



Building-Up Engineering Equipment

Just as English investigators have led the way in the development of methods for depositing thick layers of relatively hard nickel, so also has a British firm, Fescol, Ltd., pioneered in the commercial application of such work to industrial processes. Bonilla[11] has given an excellent description of British experience in salvaging worn and mis-machined parts by electrodeposition. British practice has been to operate the baths at room temperatures and at relatively low rates of deposition. Because of the long time required for heavy deposits with this practice, American industry has been slow to adopt electrocasting, but it is believed that the announcement of Wesley's rapid bath will quicken interest in the process in this country.

English experience has been that old machine parts can be repaired cheaply and often give longer life than a new part because of improved wear resistance. It should be noted again that even where the wearing surface must be of chromium, the English prefer to build up thick layers more rapidly with nickel to provide a tough supporting layer for the final thinner chromium coat.

A good example of electro-salvaging is in the power field, where the damage done to parts operating in contact with superheated steam is tremendous Such parts may be economically restored to service by plating with a heavy coat of nickel, the thermal expansion coefficient of which is much closer to that of steel than is the coefficient of chromium. This advantage, together with the good resistance of nickel to corrosion and oxidation at somewhat elevated temperatures, is also responsible for the successful use of nickel-coated steel as glass lehr rolls.

Worn armature shafts have been repaired without removal of the windings. A large user of refrigeration compressors finds that by building up worn compressor rods, only one size of rods and gland packings need be kept in stock, and the practice of turning down rods and using smaller packings can be abandoned. In addition, the life of the nickel-coated rods and the packings is superior.

Figs. 2, 3 and 4 (all of which appeared in Wesley's paper) illustrate some typical applications of electrodeposition to the building up of engineering equipment.

Wesley gives a list of existing applications of heavy nickel deposits in engineering equipment, which is reproduced below:

Armature Shafts
Cams for Viscose Manufacturing Machinery
Compressor Rods
Diesel Crankshaft Pin Bearings
Electric Motor End Frames (mismachined)
Expansion Sleeves (superheated steam)
Glass Lehr Rolls
Hydraulic Rams
Lathe Beds
Lathe Saddles
Lithograph Rolls
Paper Mill Rolls
Piston Rod Bearings
Pump Plungers
Pump Rods
Pump Shafts
Pump Sleeves
Splined Shafts
Textile Printing Rolls
Textile Spindles
Turbine Gear Shafts
Valve Stems
Wrist Pins

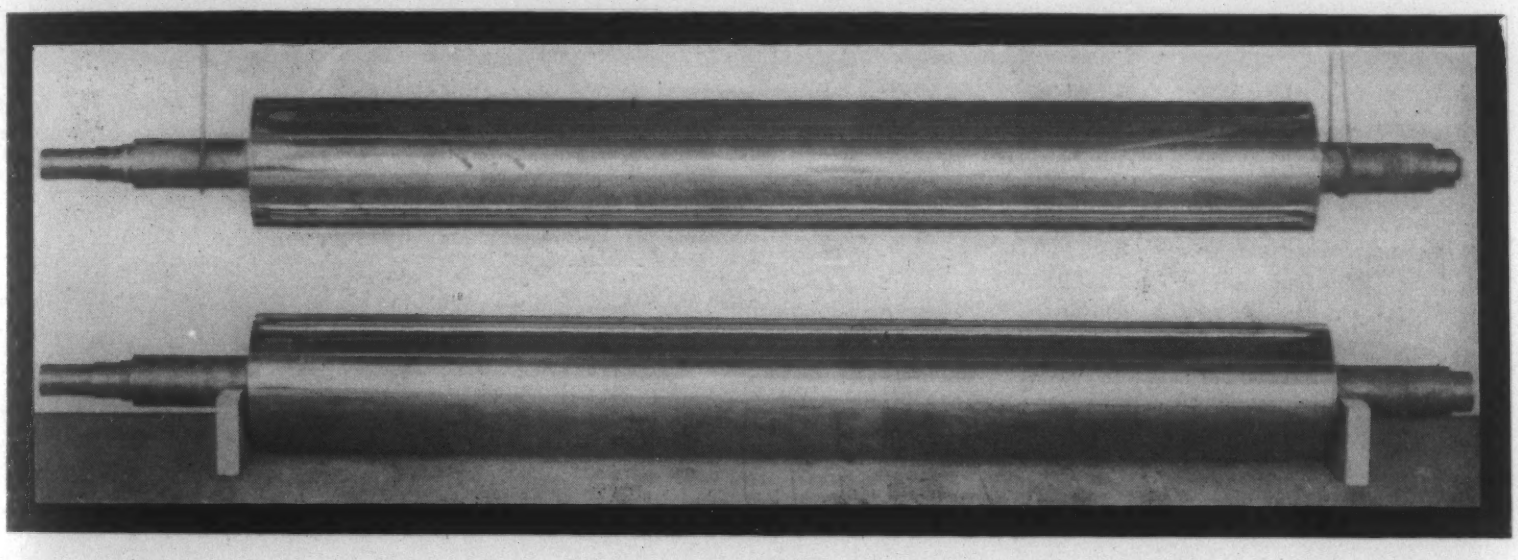


Fig. 4. Printing Press Cooling Rolls. These are steel tubes, heavily plated with nickel and chromium; length of face is 80 in. and diameter 10 in. Plated and finished by the Chromium Corp. of America.

Pore-Free Nickel Deposits

The rapidly growing engineering importance of electrodeposits, however, in no way detracts from their utility for decorative and protective purposes; methods of improving the "protectiveness" of electroplated coatings continue, therefore, to be of great interest.

Hothersall and Hammond[2] point out that the most important factor determining the protective properties of composite coatings of nickel and chromium is the porosity of the nickel undercoating. Independent work done in America,[6], France[7] and Germany[8] has proved that the porosity of nickel coatings on steel affords a reliable indication of poor resistance to atmospheric corrosion. To circumvent the bad effects of porosity, it has been necessary in the past to use

relatively heavy deposits, *i.e.* with average thickness between 0.001 and 0.0015 in., but even these have often been unsatisfactory because of variations in thickness that leave some portions, particularly of irregularly-shaped articles, with a coating of less than pore-free thickness. Obviously a knowledge of the causes and prevention of porosity will remove an important hindrance to the convenient, economical operation of nickel plating processes.

Hothersall and Hammond showed the main causes of porosity in nickel deposited on bright rolled steel to be:

(1) The presence of suspended matter in the solution, such as finely divided particles derived from the anodes.

(2) The presence of inclusions or other solid matter on the surface of the basis metal.

(3) General surface roughness, and

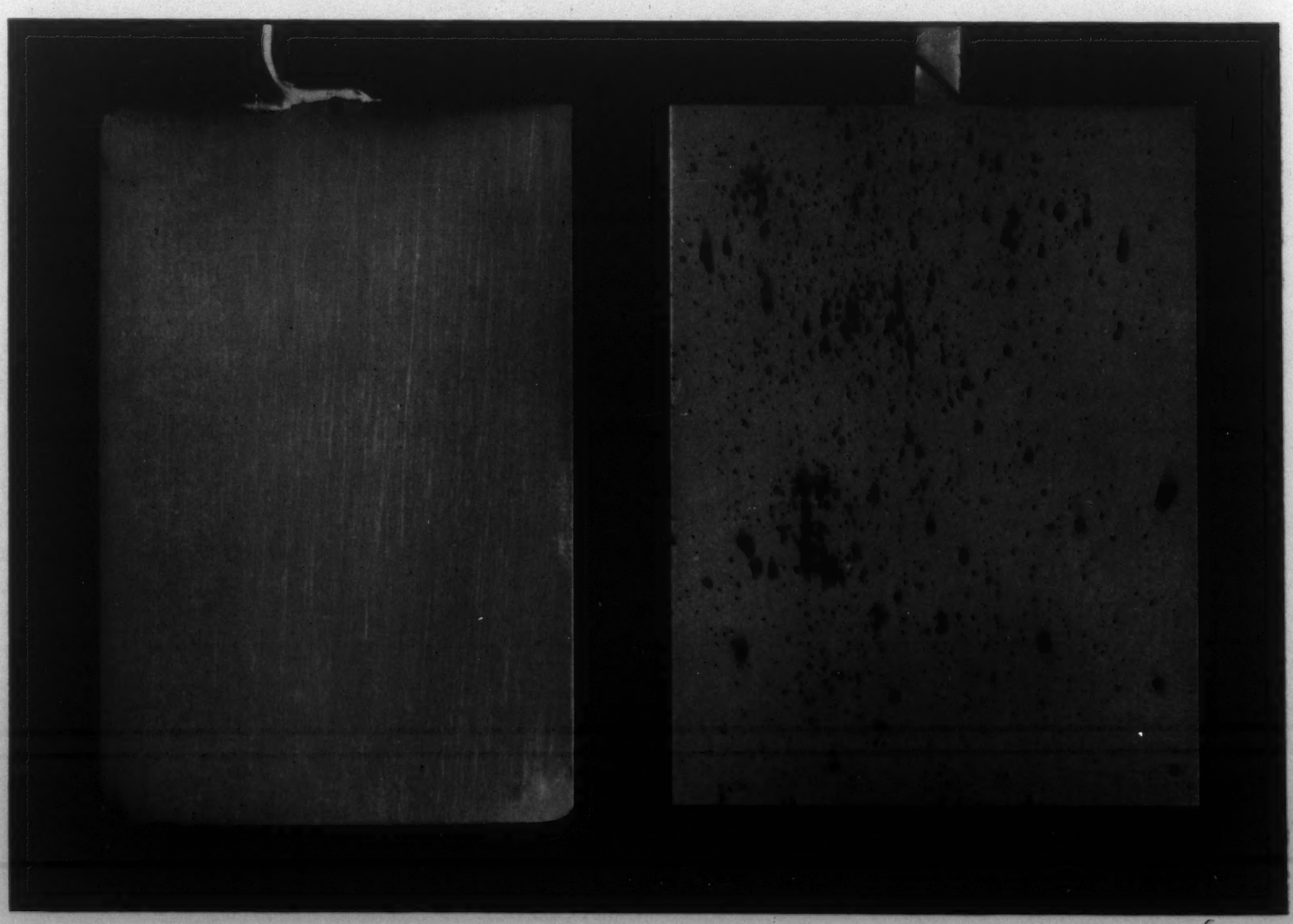
(4) The inclusion of grease or polishing compound in crevices over which a thin skin of metal (dissolved away in etching prior to plating) is flowed during polishing.

Jacquet[15] has indicated another factor that may be a cause of porosity in thin deposits—selective deposition on certain crystal faces, to the exclusion of others, in the initial period of electrodeposition. Plating conditions that affect the grain size of the plate may also be important in controlling porosity in the early stages.

Bubbles of gas adhering to the surface, or discharged and reformed continuously, do not appear to be a primary cause of porosity, nor does the effect of the pH of the solution seem to be important under the conditions studied.

Hothersall and Hammond's recognition of the previously listed causes of porosity as such was based on examination of defective deposits, and on their success in producing a pore-free 0.0001 in. deposit by a method in which each of those 4 conditions had been carefully eliminated. The method consisted in using a pure, uniformly surfaced, chemically cleaned electrolytic iron sheet as a cathode, depositing nickel on this from a practically standard plating solution prepared with special attention to purity of contents, careful filtering and protection from atmospheric dust contamination, and employing platinum anodes separated from the cathode by specially-cleaned alumina filtering thimbles. Fig. 5, taken from Hothersall and Hammond's paper, shows, for example, the improvement in porosity obtained by

Fig. 5. Effect of Basis Metal on Porosity. At left, nickel-plated electrolytic iron; at right, nickel-plated rolled mild steel. Both specimens were plated with 0.00012 in. of nickel, then subjected to the hot water test before photographing. Rust spots indicate the existence of pores; note complete absence of pores in the specimen at the left. From Hothersall and Hammond.[2] (Courtesy The Electrochemical Society.)



using a specially prepared electrolytic iron sheet in place of bright rolled mild steel as the basis metal. There may, of course, be other types of surface just as suitable as that used by Hothersall and Hammond.

There is, of course, the possibility that some causes of porosity not considered by the authors were eliminated along with the recognized causes when this "ideal" plating process was set up, and, therefore, that the list of causes may not be complete. This is highly improbable, however, in view of the exhaustive listing and analysis of "possible" causes of porosity made by the authors at the start of their work. The authors do recognize that the four causes they finally isolated, although real, are rather general, and hope to show in later contributions what specific types of surface and solution defects are most responsible for porosity troubles, and what commercial precautions can be taken to avoid them.

Even in the absence of this more specific information, the work reported represents a tremendous step forward, for it has shown, first, that microscopically-thin, pore-free nickel deposits *can* be produced and, second, that the requisite general conditions for their production are not outside the scope of commercial possibility. It is not too strong a claim to make that the control of such conditions in a plating shop operating continuously can be developed gradually through accumulated experience, in much easier fashion than in a laboratory, which requires artificial means to produce the desired effects in one experiment or in one series of experiments. Continuous filtration of solutions, protection of processes from atmospheric contamination, and uniform-surface preparation of steel are commonly and efficiently accomplished in many other fields and in some electroplating plants as well. It seems entirely possible that with care and improvement in plating practice and further progress by the steel industry in producing a suitable surface for plating, a much closer approach, at least, to Hothersall and Hammond's ideal conditions is possible than we have heretofore attained.

Conclusion

The developments described by Wesley will not surprise the up-to-date plater. The metallurgical engineer, however, has not yet accepted plating as a tool of his profession. Electrodeposition has interested chiefly the chemist, who knows little about the structures, habits and uses of metals, while the metallurgical engineer, who knows all about these things, has rarely seen a piece of electrodeposited metal able to stand up alone. It is with the engineer's needs in mind that this résumé has been presented. Other important advances in nickel plating have recently been announced, to be sure—among them refinements in, and broadening application of rapid nickel plating, bright nickel, the electrodeposition of alloys, the successful commercial plating of other metals on aluminum, etc., but none offers the great possibilities for useful industrial service that reside in the production of pore-free deposits and, particularly, in the control of engineering properties of heavy electrodeposits.

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A CHUCKLE

Furnace Atmospheres

Perhaps the following excerpts from a newspaper write-up of a recent steel plant accident might be as amusing to some of your readers as they were to me, particularly in view of the recent literature concerning furnace atmospheres.

"The blast came while ...., ..., and .... were connecting a natural gas line to a deoxidizing machine, which treats the gas for annealing purposes. ..... Officials of the plant said that the DEODORIZING machine takes oxygen from natural gas to prevent it from rusting metal that is being annealed."

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Advantages of Titanium in Low A

There is wide interest in the low alloy, high strength steels, particularly as to their welding properties. This article is an extended abstract based on a discussion by Swinden and Reeve, entitled "Metallurgical Aspects of the Welding of Low Alloy Structural Steels," which was published in the Transactions *of the Institute of Welding, London, January, 1938, Vol. 1, page 7. The discussions of this paper are also reviewed.—The Editors.*

Welding with an Atomic Hydrogen Arc (Courtesy: General Electric Co.)

Alloy Structural Steels for Welding

by GEORGE F. COMSTOCK

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ALTHOUGH MILD STEEL PLATES can be welded without difficulty for structural uses, the "low alloy" steels having tensile strength of 74,000 to 100,000 lbs. per sq. in., yield point over 51,500 lbs. per sq. in. and up to 0.30 per cent carbon have given considerable trouble when welded, on account of the formation of a hard and brittle zone in the plate adjacent to the weld. This trouble is more serious with higher carbon contents, and therefore some alloy content, rather than higher carbon, is used for improving the strength. For equal strengthening additions, carbon gives the greatest hardening, and molybdenum (although "not usually added in substantial amounts") the next; other elements are effective as hardeners in the following order: Chromium, manganese, copper, nickel, and silicon, the last having the least hardening effect per given residual alloy content.

Mitigating Hard and Brittle Zones

All low alloy, high strength structural steels now in use, when welded, will form a hardened zone next to the weld, and sometimes this zone is even cracked. The hardness and brittleness of this zone may be mitigated by proper welding technique, and by metallurgical practice, so that, in spite of its presence, the welds of these steels may be satisfactory. Metallurgical expedients for minimizing the "brittle zone" trouble are:

(1) Selecting the combination of alloying elements having the least hardenability factor.

(2) Maintaining the carbon below about 0.12 per cent, and relying on alloying elements to strengthen the ferrite.

(3) "Controlling the hardenability of higher carbon, high tensile steel by the addition of alloys exercising a controlled inhibition of the hardenability," or in other words, adding titanium.

For practical purposes the authors have rejected the first two expedients mentioned, on account of the expense of the desirable alloys required for making a steel of over 75,000 lbs. per sq. in. tensile strength, especially with a very low carbon content, and they studied in considerable detail the possibilities of titanium additions, as mentioned under item No. 3 above.

Preliminary tests of 18-lb. induction furnace melts of 0.25 per cent carbon steels with titanium up to 1.6 per cent are reported in Table 1. The test bars were forged to 5/8 in. diameter and normalized at 1650 deg. F.

These results show that a titanium to carbon ratio between 2 and 3.5 is best for strength, yield ratio, ductility and toughness. Metallographic studies indicated that "titanium progressively supplants iron in the carbide formed, with the result that the carbon change point on heating is gradually suppressed; and that the titanium carbide goes into solution very slowly at a much higher temperature, above 1830 deg. F. It was found by experiment that the hardenability developed in welding ½-in. plate under drastic conditions corresponded approximately to a water quench from about 1830 deg. F." The hardness results in the Table show a marked difference between the untreated and the titanium steels after quenching from temperatures between 1,650 and 1,920 deg. F., the titanium steel hardening much less, so that the hardened zone adjacent to welds in that steel would be less intense or brittle than in the untreated steel.

Tests of Steel Made in Open-Hearth Furnace

Further results are reported on a steel produced commercially in an open-hearth furnace and having the following composition:

	Per Cent
Carbon	0.15
Manganese	1.44
Silicon	0.16
Sulphur	0.03
Phosphorus	0.04
Copper	0.20
Titanium	0.37

The titanium was obtained from a low-carbon ferroalloy containing about 40 per cent titanium, 15 per cent copper and 10 per cent aluminum, and in this instance it was added in the mold, and without any other addition of aluminum. The authors have also used ladle additions of titanium however, and have no particular preference for that type of ferro-titanium. (Communication from Dr. Swinden.)

When rolled into plates and normalized at 1,650 deg. F., this steel gave the following tensile test results, had an Izod impact value of 85 ft. lbs., and could be bent flat without fracture. (Table 2.)

A similar steel without titanium, in the form of ½-in. plate, would have a tensile strength of about 78,400 lbs. per sq. in., a yield point of about 51,500, and 0.66 yield ratio. The titanium addition thus raised the tensile strength 8.7 per cent, the yield point 29.4 per cent, and the yield ratio 18.2 per cent., still giving ample ductility and impact resistance.

The improvement in lessened hardenability was confirmed in a number of welding tests carried out on these titanium steels. An example of such a test on ½-in. butt-welded plates of the same "manganese-copper" steel mentioned above is given below. The welds were made with a single sealing run, using a "high tensile electrode" in a 60-deg. single V notch. Tensile tests were made with parallel-sided specimens, both breaking in the plate. The bend tests were not strictly comparable, that on the titanium steel having been made around a 1-in. pin, with that on the untreated steel made less severely around a 2-in pin.

Kind of steel	Titanium	Non-Titanium
Tensile strength of weld	83,500	83,000
Elongation on ½ in. in bending	49 and 54%	33%
Reverse bend, root of weld outside	25%	10-15%
Izod value, center of weld	51 and 67	45 and 53
Izod value, edge of weld	71.5 and 71.5	45 and 60

Although these results are admitted not to demonstrate necessarily the weldability which may be expected under shop conditions, the marked elongation of the welded titanium steel in the bend test is considered to be of great practical interest. This improvement in ductility is probably due to the absence of hardening and also to the higher yield point of the titanium steel.

In actual welding of plates in large structures other factors, such as the placing of several runs of weld metal on top of each other, and the prevention of expansion or contraction across the weld by rigidity of the structure, affect the quality of the finished joint. The rigidity or "restraint from movement" is what causes welds to crack soon after they cool, the cracks being actually due to shrinkage stresses combined with the hardening (or loss of ductility) of the plate adjacent to the weld.

The influence of titanium in reducing the degree of weld hardening produced by a single fillet weld in high tensile steel is illustrated by two examples, both made with ½-in. plates of about 89,500 lbs. per sq. in. tensile strength, using a mild steel electrode. The maximum hardness near the weld was 406 Vickers with the plain steel, and 298 with the titanium steel; the hard zone was only about a third as wide in the latter steel as in the former, and the microstructure was sorbitic instead of martensitic. The reduction in width of the hardened zone was believed to be due to the "fine grain and resistance to grain growth of the titanium steels."

Test for Cracking Tendency

A special test and test specimen for determining the cracking tendency of high tensile steel during welding is described in detail. The degrees of cracking seen after making this test are classified in accordance with the refinements of polishing, etc., required for observing the cracks. "High tensile electrodes" invariably produced severe cracks in this test, as well as in shop welding when the joints welded were restrained from movement. The heaviest possible flux coatings on the electrodes improve the results.

"With the titanium high tensile steels" the authors' "results have been very much better, as would be

Table 1.—Preliminary Tests of Induction Furnace Melts

Heat No.	1531	1534	1529	1649	1591	1635	1764	1747	1760
Carbon	0.25	0.26	0.25	0.28	0.27	0.27	0.27	0.28	0.23
Manganese	0.41	0.54	0.46	0.40	0.59	0.56	0.60	0.63	0.59
Silicon	0.14	0.15	0.22	0.26	0.24	0.24	0.22	0.25	0.44
Titanium	None	0.21	0.41	0.62	0.76	1.05	1.12	1.60	1.60
Ti-C ratio	0	0.80	1.60	2.20	2.80	3.90	4.10	5.70	7.00
Tensile strength	75,200	81,900	77,000	79,800	78,200	76,400	73,200	60,600	.....
Yield point	52,800	60,000	55,500	62,900	62,600	58,800	53,300	30,900	.....
Yield ratio	0.70	0.73	0.75	0.79	0.80	0.77	0.70	0.51	.....
Elongation in 2 in.	34.5	31.0	31.0	33.0	34.0	33.0	35.0	39.5	.....
Reduction of area	63.6	63.6	63.6	63.6	66.0	68.0	70.0	68.0	.....
Izod value	82	91	93	96	104	108	104	39	.....
Vickers Hardness No. on Specimens Quenched from:									
1560° F.	238	...	222	...	181	181	...	...	112
1650° F.	404	...	221	...	215	188	...	...	112
1740° F.	413	...	233	...	209	198	...	...	111
1920° F.	396	...	301	...	251	212	...	...	120
2010° F.	366	...	292	...	258	233	...	...	176
2190° F.	364	...	311	...	308	308	...	...	206
2280° F.	364	...	385	...	308	328	...	...	233
2370° F.	...	...	385	...	360	360	...	...	...

Table 2—Properties of Steel Normalized at 1650 deg. F.

Thickness of plate	⅜ in.	⅜ in.	½ in.	½ in.	⅝ in.	⅝ in.
Direction of test	Lengthwise	Transverse	Lengthwise	Transverse	Lengthwise	Transverse
Tensile strength	88,500	89,400	84,800	85,700	87,400	86,900
Yield point	67,200	68,200	65,600	67,700	66,500	64,000
Yield ratio	0.76	0.77	0.78	0.79	0.76	0.74
Elongation in 8 in.	19.5	19.0	20.5	21.5	21.0	22.5
Reduction of area	63.1	62.0	66.0	64.0	60.9	59.2

expected from their considerably lower degree of hardenability. In the crack test the lower tensile grades of this steel are free from all cracks with all electrodes; the higher tensile grades may develop very fine micro-cracks when using the least satisfactory of the high tensile electrodes, while, with more suitable grades, cracks will be entirely absent."

Dead soft mild steel electrodes gave good results in welding high tensile steels. Although the hardened zone was present in such welds, cracks were not formed. To prevent cracking, the all-weld-metal should contain less than 0.10 per cent carbon (preferably below 0.08%), less than 0.30 per cent manganese, and less than 0.05 per cent silicon. Austenitic stainless steel electrodes also give good results. Finally the authors discussed "welding technique," showing that with other conditions unchanged the following expedients prevented cracking: "Multirun welding;" preheating; and stress-relieving by heat treatment. The electrodes should not be too large, nor the speed of welding too great.

Prof. B. P. Haigh in the discussion suggested that the lack of cracking with the titanium steels was due to the critical point occurring at higher temperature, where the transformation of martensite would not result in a contraction of volume, as would occur with a lower transformation temperature.

Quench-Aging Effects

Dr. Swinden in reply to a question said that no serious quench-aging effects had been found in these titanium steels. "The impact value was maintained at least after a week's aging on quenching from 1,200 deg. F. for example." Since the publication of the paper, however, some evidence of precipitation hardening has been found in low carbon titanium steel containing 0.07 per cent carbon, 1.01 per cent manganese, 0.32 per cent silicon, 0.21 per cent copper, and 0.28 per cent titanium, and this subject is being investigated further. (Personal communication from Dr. Swinden.)

Another question was how titanium could raise the tensile strength and yield point, while at the same time reducing the hardenability. The authors explained this in the following way in their written reply: When sufficient titanium is present in steel, the carbon certainly occurs as titanium carbide, which completely dissolves only at a very high temperature, well above 1,830 deg. F. Quenching such a steel from a temperature up to about 1,830 deg. F. is therefore analogous to quenching a straight carbon steel from a temperature below 1,290 deg. F. "If such a steel were quenched from a temperature beyond which the titanium carbide went into solution the full hardness was produced."

In steel containing 0.25 per cent carbon and 0.4 per cent titanium, a portion of the carbon would exist as "iron carbide or possibly a double carbide with titanium." The carbide was found to be present in a very fine form in such steels in the normalized condition. This caused the tensile strength, yield point, and impact value to be slightly higher than those of a similar steel without titanium. When these steels were quenched from 1,650 deg. F. however the hardness with titanium was only 221 as compared to 404 without titanium, indicating that the titanium carbide had not gone into solution at 1,650 deg. F. "The better mechanical properties in the normalized condition were probably due to the better structure of the material, on account of the presence of titanium."

The data on quenched samples showed that there was a gradual solubility of titanium carbide with increasing temperature above a certain minimum temperature depending on the titanium content. Very long soaking would probably be necessary to achieve complete equilibrium.

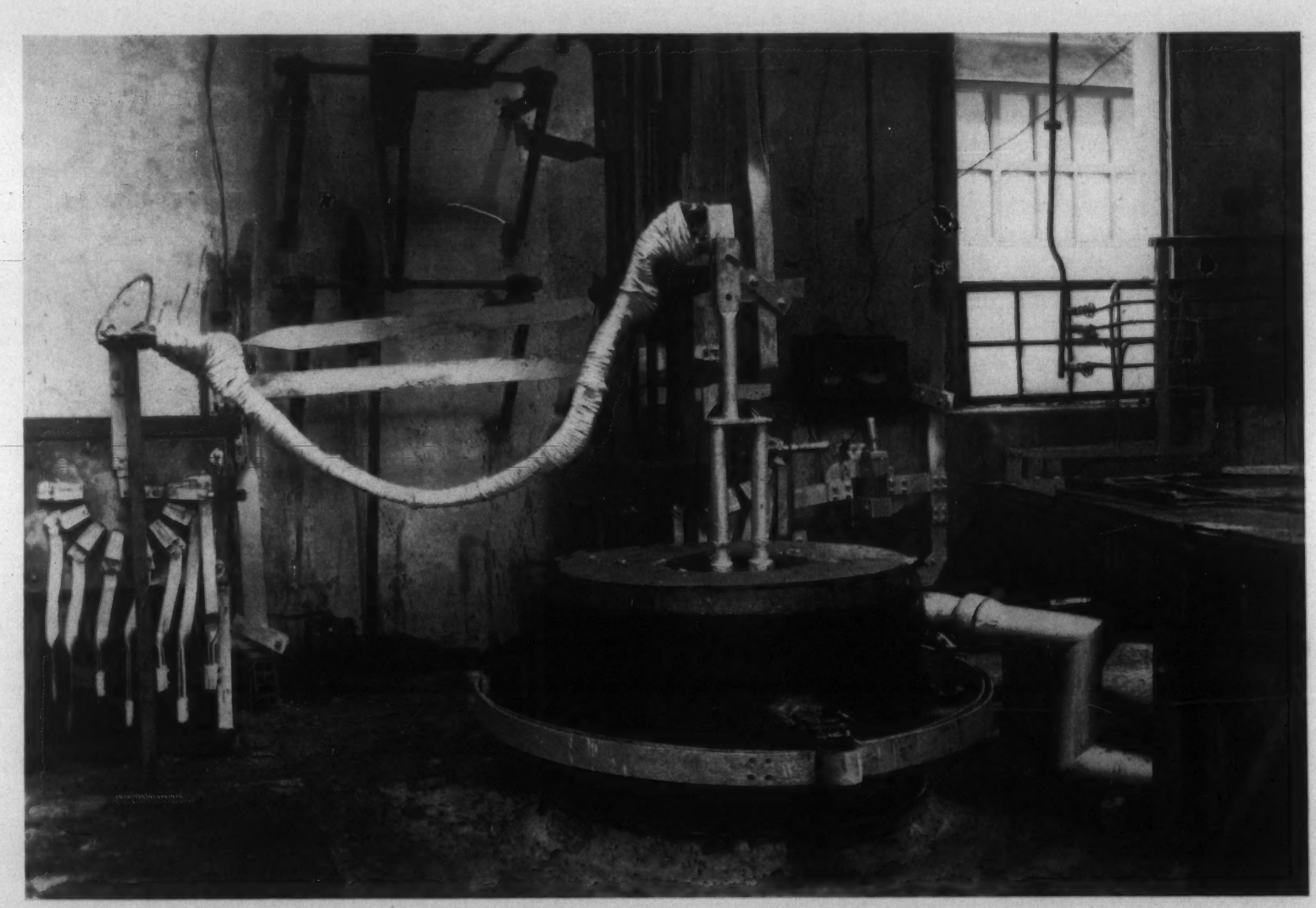
Most of the discussion dealt with various aspects of welding technique, rather than with the properties of steels, and is therefore not reported in this abstract. The authors stated in their final reply that although the problem of welding high tensile steel can be solved to a certain degree by suitable electrodes and welding technique, still the steelmaker's contribution of the new titanium steel was believed to afford a solution which "would be found worth while for certain purposes."

Electric Welding of Steel (Courtesy: Bethlehem Steel Co.)

PROPERTIES AND METALLURGICAL USES OF

Calcium

Calcium is fast becoming an important metallurgical raw material, for although it is not a "tonnage" product in itself, relatively small amounts have a great effect on the properties of materials to which it is added. In this article, which is based on a paper read at a meeting of the A. I. M. E., the authors give a useful compilation of the properties of calcium and discuss in some detail its use as a scavenger and alloying element for a wide range of ferrous and nonferrous metals and alloys.—The Editors.



One of the Early Cells for the Manufacture of Calcium.

—A CORRELATED ABSTRACT

by C. L. MANTELL and CHARLES HARDY

Consulting Engineer, New York, and President, Charles Hardy, Inc., New York, Respectively

In the past few years, the alkaline earth metals have been receiving increasing industrial attention. The most important commercial member of this group is calcium, a metal available in larger quantities and at a lower price than is generally realized.

The physical and chemical properties of calcium have been insufficiently appreciated. Its ramified uses in industry have gone largely unnoticed and its very interesting specialized possibilities have not received the attention they deserve. Many of us are inclined to think of calcium as being similar in properties and

applications to sodium, although this is decidedly not the case.

Some twenty years ago the price of calcium was in the neighborhood of $20.00 a pound. In 1934 the price was of the order of $1.50, while at the present time for metal 98.5 to 99 per cent pure and furnished in irregular lumps of 5 to 10 cm. size packed in 100-lb. tin-lined cases or 10-lb. tin cans, the price is of the order of $0.75 to $1.00. Commercially, the metal is available in both the technical purities and as sublimed material of unusually high quality.

Physical and Chemical Properties

In its commercial form, freshly cut calcium is silvery white; fractured surfaces are more brilliant than steel. Such surfaces exposed to moisture-bearing atmospheres develop thin films of bluish-gray oxide, which are protective against further attack. Unlike sodium or the other alkali metals, calcium may be allowed to come in contact with the skin, without danger; it may, in general, be handled like magnesium and aluminum. Calcium is heavier than sodium and the alkali metals, but lighter than beryllium, magnesium or aluminum. For equal cross-sectional area, its electrical conductivity is exceeded only by that of silver, copper, gold or aluminum. Thus, for equal weight and length, calcium is among the best available conductors.

Calcium is ductile and malleable. It can be machined in a lathe, turned into shapes, drilled, threaded, sawed, extruded, pressed, hammered into plates, and drawn into wire. Its commercial forms include chunks, bars, shavings, rods and, very recently, powders.

The physical and chemical properties of calcium are given in Table I.

Impure calcium containing 86.7 per cent calcium, 9.1 calcium oxide, 2.7 calcium chloride, 0.35 silicon, 0.88 iron, and 0.2 aluminum distilled in vacuum and remelted under argon, produced sound metal containing 99.3 per cent calcium, 0.02 iron, 0.14 silicon and traces of chlorine.[14] This material showed two transformation points, one at 430 and another at 240 deg. C. Graf[18], using calcium of 95.4 per cent purity, observed an allotropic transformation at 450 deg. C., with a change from face-centered cubic to body-centered cubic lattice; Schulze and Overberg[19] also observed a polymorphous transformation between 430 and 450 deg. C. The existence of the body-centered lattice seems to depend on impurities, and it is believed that above 450 deg. C. the lattice of pure calcium is hexagonal close-packed. Despite the evidence of a transformation somewhere between 240 and 300 deg. C., the lattice type between 300 and 450 deg. C. has never been definitely determined.

The ductility of calcium is greatly affected by impurities. With a loading speed of 4 mm. per min., distilled calcium is more ductile than aluminum of 99.6 per cent purity and less ductile than lead, but it has a greater elongation than either. No creep was observed on loading calcium at room temperature with less than 570 lbs. per sq. in.

Crushing tests showed complete recrystallization of calcium at 300 deg. C. and above during deforma-

Table I—Physical and Chemical Properties of Calcium

		Reference
Atomic number	20	
Atomic structure		
Room temperature	Face-centered cubic	(2)
Above 450°C., pure	Hexagonal close-packed	(1)
Above 450°C., impure	Hexagonal or body-centered cubic	(1)
Atomic weight	40.07	
Atoms per cube	4	(2)
Boiling point	1170°C. (2138°F.)	
Compressibility, average At 20°C., between 100 and 500 megabars/cm.^{2}	5.7×10^{-6}	(4)
Elastic limit		(3)
Distilled	1,465 lbs./in.^{2}	
Extruded wire	5,545 lbs./in.^{2}	
Electrical conductivity At 20°C., Ag = 100	45.1	
Electrical resistance At 0°C.	3.43 microhms/cm.^{3}	(5)
Electrochemical equivalent Mg./coulomb	0.20762	
Elongation, per cent		
Distilled	53	(3)
Extruded wire	61	
98.5% Ca	30.5	
Impure	None	
Extrusion temperature (distilled)	420°-460°C. (788°-860°F.)	(3)
Freezing point	809°-810°C. (1488°-1490°F.)	(7)
Hardness (Brinell, 500 kg. load)		(3)
Distilled Ca (Pomey & Voulet)		
Below lower critical point	14	
Above lower critical point	17	
Above upper critical point	27	
Extruded wire	17	
Heat of evaporation (solid) T = O	4.53×10^4 cal./mole	(8)
Heat of transformation	2.3 calories	(9)
Latent heat of vaporization	399 kilojoules/gram atom	(10)
Melting point		
Commercial product	810°C. (1490°F.)	
In argon	851°C. (1563.8°F.)	(12)
Modulus of elasticity (distilled)	3,200,000-3,900,000 lbs./in.^{2}	(3)
Recrystallization temperature	345°C. (653°F.)	(1)
Specific Gravity		
Distilled, at 20°C.	1.542	(3)
Extruded wire,		
α-phase, 450°C.	1.48	(1)
β-phase, 480°C.	1.52	(1)
Specific heat		
—185° to +20°C.	0.157	
0° to 100°C.	0.149	
Temp. coeff. elec. resistance	0.00457	
Tensile strength		
Distilled	6,050 lb./in.^{2}	(3)
Extruded wire	8,105 lb./in.^{2}	
Thermal expansion, linear, 0-300°C.	2.2×10^{-5}	(11)
Valence	2	
Vapor pressure, mm. Hg		(13)
At 300°C.	9.6×10^{-8}	
At 1000°C.	47.2	

A Redistilled Crystal of Metallic Calcium.

tion. The pressure required for deformation decreases with the temperature and has a sharp break at 440 deg. C., which corresponds to the beta-gamma transformation temperature. Gamma-calcium deforms plastically under very small loads. Calcium wire could be easily extruded between 420 and 460 deg. C.

The vapor pressure of solid calcium between 500 and 625 deg. C. was measured by the method of molecular diffusion.[15] Microtitration methods were used to determine the amount evaporated, which could be determined within 10^{-6} gram. The results are represented by the empirical equation log p (in mm.) = 8.15 — 9670/T. The present values for the pressure are about 1/10 of those previously reported by Pilling[16] for the same temperature. Because the specific heat of solid calcium is known as a function of T, the "chemical constant" can be calculated. The new pressure data lead to the correct value for this constant, but the old do not.

Calcium cannot be cast by ordinary foundry methods, as it oxidizes readily at elevated temperatures. Oxidation is exceedingly rapid at its melting point (around 800 deg. C. for the commercial, impure metal); nitrides lower the melting point.[17] Melting and casting procedures employing protective fluxes or operations conducted in the presence of reducing or inert gases allow the production of cast forms of the metal.

Calcium is more active chemically than barium or strontium. On a price basis, calcium is by far the cheapest of the alkaline earth metals, but is more expensive than sodium, which is lower in atomic weight and cheaper in cents per pound. In organic syntheses, sodium is in a better competitive position. However, sodium is not suitable for metallurgical work as a deoxidizing agent, reducing agent, degasifier, and alloying metal, because of its low melting point and high vapor pressure.

Table II—Operating Details for Electrolytic Production of Calcium

Electrolyte	Pure calcium chloride
Temperature, deg. C.	780-800
Current:	
Current density, amps./sq. in. cathode	650 (100 amps. per sq. cm.)
Energy consumption	30,000 to 50,000 kw.-hrs./ton, 15-25 kw.-hrs./lb.
Theoretical decomposition voltage of $CaCl_2$ at 800 deg. C.	3.2[20]
Melting point of $CaCl_2$, deg. C.	780
Specific conductivity of $CaCl_2$ at 800 deg. C.	1.9[21]
Lb. $CaCl_2$/lb. Ca (theoretical)	2.76
Lb. $CaCl_2$/lb. Ca (actual)	4-5
Anodes	Graphite
Cathodes:	
Material	Iron or graphite coated with calcium
Type	Vertical, with surface contact
Cells:	
Lining	Carbon
Casing	Sheet steel

Production of Calcium

The production and consumption of barium and strontium are very small in comparison with calcium. Because of the low atomic weight of calcium, 40 pounds of it is equivalent in reducing power to 137 pounds of barium, a ratio of more than 3:1. It is much cheaper than barium and for chemical purposes is the most economical of the alkaline earth metals.

Calcium is produced by the electrolysis of fused calcium chloride or by the distillation of calcium from its compounds, of which the silicide is an example. Owing to hydrolysis and the formation of basic salts, pure anhydrous calcium chloride can be prepared only with difficulty. In the presence of basic salts, calcium metal is attacked and dissolved by the electrolyte to the extent of 17 per cent. During electrolysis, if basic salts are allowed to form, the bath thickens, the conductivity decreases, and the calcium yield falls off. In commercial work the electrolyte must be completely changed at periodic intervals. Calcium oxide is soluble to the extent of several per cent in fused calcium chloride, and the basic salts are thought to be oxides of magnesium, perhaps with carbides of calcium.

Pure calcium chloride melts at 780 deg. C. and impure calcium metal at 800 deg. C. The range of safe working temperatures is small, as the finely-divided metal burns in air above 800 deg. C. and easily forms metal fog in the electrolyte. The decomposition voltage of calcium chloride at 800 deg. C. is given at 3.24 volts,[20] while the specific conductivity at the same temperature is 1.9.[21]

The commercial method for calcium production uses a vertical contact cathode, upon which the calcium is deposited as the cathode is continuously moved upward. The operating details are given in Table II.

In reference to the energy consumption figure in Table II, the variation between 30,000 and 50,000 kw.-hrs./ton is a function, first, of the size of the furnaces employed; second, the details of construction

and the carefulness of insulation of these furnaces; and third, the length of the operating campaign before changes need to be made either in the electrolyte, in the cell proper, or in the electrical connections. The lower figure is obtainable with large cells and long campaigns, while the higher figure is encountered in connection with small cells either infrequently operated or producing calcium metal for only short periods.

Low recovery values of calcium chloride in terms of calcium metal are chiefly due to the atomizing effect of the violent chlorine evolution. This causes a fine spray of electrolyte which is carried up the flue of the ventilating system. Other losses are due to the necessary skimming of the bath at intervals and to the layer of chloride formed on the calcium as it is drawn from the bath. Once in operation, the cathode is effectively one of calcium metal. Thin layers of calcium chloride protect the metal from the air. The commercial metal may contain small quantities of carbon, carbide, and alkali and alkaline earth metals.

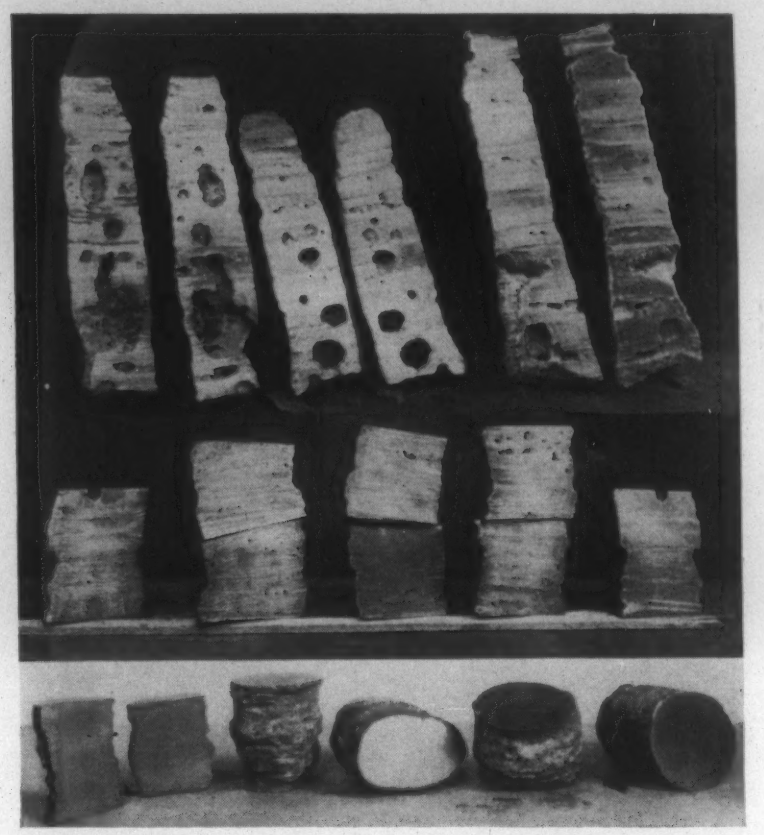
Applications of Calcium Metal

Calcium burns brightly in oxygen, combines with sulphur, chlorine, nitrogen and other materials, and reduces nearly all metallic oxides on heating. Calcium is used in freeing absolute alcohol and other organic liquids from the last traces of water. If the metal be heated in a tube connected with a vessel at low pressure, the last traces of air are taken up with the formation of stable oxides and nitrides, whereby the pressure in the system is reduced to very low values.

Calcium alloys with barium, aluminum and magnesium find application in "getters" in radio and vacuum tube manufacture, for removing the last traces of objectionable gas from the "vacuum." The metal may also be used by itself for the same application in the form of pellets or as wire, or as wire coated with magnesium, or in other shapes. A considerable number of these applications, of the "secret process" type, exist.

Many uses of calcium in conjunction with lithium, lithium and silicon, or other alkali or alkaline earth metals have been suggested.[22] For special purposes furnace-quality calcium metal can be distilled and very pure products produced, or it may be subjected to sublimation without fusion.[23]

Inasmuch as calcium does not react with argon, it is employed for the separation of argon from nitrogen. When rapidly heated in CO_2, the metal is converted to lime and calcium carbide (CaC_2). The hydride CaH_2 is formed by passing hydrogen over heated calcium, and in a similar way the nitride Ca_3N_2 is produced by passing nitrogen over the metal. When heated in ammonia, calcium forms the hydride and nitrogen. Calcium nitride, when reacted with steam, gives off ammonia.



Improvement in the Soundness of Metallic Calcium Manufactured in Recent Years. Top—Calcium as produced 5 yrs. ago; Middle—Calcium as produced 2 yrs. ago; Bottom—Calcium as produced today.

Calcium hydride itself is an interesting article of commerce. Hydrogen reacts with calcium at 700 deg. C. to form calcium hydride, CaH_2.[24] This product may be used as a source of "nascent" hydrogen for the liberation of metals from difficultly reduced oxides.[25] The hydrides are dissociated on heating above 300 deg. C., giving off large volumes of nascent hydrogen whose reduction effect is markedly greater than molecular hydrogen. The hydrides are employed as a source of pure gas. They offer new possibilities in the production of alloys, because of the liberation and protective effect of nascent hydrogen during alloying. In general, the metallic hydrides are more convenient to handle than are finely divided metals in the degassed state. By the use of calcium hydride, pure titanium, zirconium, thorium, and uranium may be produced from their refractory oxides, and alloys of these elements with copper, nickel and other non-ferrous metals are readily made.

The current industrial applications of calcium metal are listed below. Each of these will be discussed to some extent.

Alloy agent for:
  Aluminum, bearing metals, beryllium, copper, iron, lead, magnesium.
Controller for graphitic carbon in cast iron.
Debismuthizer for lead.
Decarburizer and desulphurizer for ferrous metals and alloys.
Dehydrating agent for:
  Alcohol, solvents and organic liquids.

Deoxidizer for:
Chromium-nickel, copper, iron, iron-nickel, nickel, nickel-chromium-iron alloys and steels, nickel-bronzes, steel, tin-bronzes

Desulphurizer for petroleum fractions.

Evacuating agent for high vacua.

Getter alloys in radio tubes.

Modifying agent for aluminum, beryllium and magnesium alloys.

In preparation of:
Bearing bronzes of high lead type, chromium-nickel to prevent formation of chromium carbide, chromium-nickel steels, copper-calcium alloys, lead alloys, pure nickel castings to reduce defects, 50 nickel-50 iron and other alloys to eliminate cracking during hot working.

Reducing agent in preparation of:
Chromium metal powder, thorium, uranium.

Separator for argon from nitrogen.

Uses of calcium-iron:
Deoxidizer for iron castings in green sand molds.

Uses of calcium-lead:
Battery grids and plates; bearings; debismuthizer for lead; sheathing for telephone, cable and electric lines.

Preparation of Chromium, Thorium and Uranium Metal Powders

Metallic chromium powder[26] as well as metallic thorium and uranium may be produced either by electrolytic methods or by the reduction of the corresponding oxides by the use of calcium metal in the presence of calcium chloride as a flux. The oxide, calcium chloride, and finely-cut calcium are mixed together and introduced into a bomb, which is sealed with a tapered stopper and heated to red heat or to a temperature of approximately 900 deg. C. The calcium serves as a reducing agent, being itself converted to the oxide. After the reaction is completed, the bomb is allowed to cool, the charge removed, disintegrated in cold water, washed in dilute alcohol, and the metallic powder separated. The chromium, thorium or uranium metal is then sintered into ingots and made into mechanically worked forms and shapes.

The reduction of vanadium pentoxide with calcium in a mixture of fused calcium chloride and barium chloride yields a semicolloidal powder which cannot be converted into a workable form by pressure and heat.[27] If the powder be mixed with more calcium and the mixture heated with calcium chloride and barium chloride, the resulting metallic powder can readily be pressed into slugs which, after sintering in vacuum in an induction furnace, can be cold forged and rolled. Workable thorium can be prepared in a similar way. Both vanadium and thorium sheets are embrittled by heating in barium chloride, but can be annealed in borax. Reduction of uranic oxide (pitchblende) with calcium under fused chlorides gives a powder of which part is colloidal and pyrophoric, but the heavier particles can be pressed and sintered into a workable form; on cold working, this metal tends to crack and oxidize in the cracks.

Debismuthizing of Lead

Calcium is an effective agent for the debismuthizing of lead to make it suitable for white lead manufacture. When metallic calcium is introduced into molten lead, calcium-bismuth drosses are formed. The bismuth content is reduced to less than 0.05 per cent and the last traces of arsenic, antimony, silver and copper are removed. Lead-calcium alloys containing approximately 3 per cent calcium are, in a manner similar to the desilverization of lead bullion with zinc, stirred into the lead by a mixing machine. Other processes, such as cooling, blocking out, and reducing the bath close to the freezing point of lead, are similar to desilvering operations. Excess calcium remaining in the lead is removed by chlorination. Considerable development of the process has been carried on by the American Smelting and Refining Company.[28-30]

(To be continued)

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[26] J. W. Marden and M. N. Rich. U.S. Patent 1,760,367, May 27, 1930.

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[28] J. O. Betterton, of American Smelting and Refining Co. British Patent 370,026, Oct. 31, 1929.

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Nickel-Lined Heat-Treating Tanks

AS PART OF THE EQUIPMENT for a special heat-treating plant at its Alcoa (Tenn.) plant, the Aluminum Co. of America needed some very large steel tanks specially lined with a protective metal. Details of the heat-treating process are not available but it can be stated that an electrically heated salt bath is used.

To protect the steel from the action of the salt bath, these large tanks had to be lined with nickel. The order for the tanks was placed with the A. O. Smith Corp., Milwaukee, Wis. Nickel sheet was welded to the inside of the steel tanks by the special "Smithlining" process. According to a description of this process by the Smith corporation, the lining sheet is inseparably attached to the steel walls of the tank by a special electric welding process. Vessels thus lined are described as combining the economy, safety and strength of the usual run of carbon steels with the desirable properties and features of the stainless metals or alloys. These include corrosion resistance, freedom from discoloration and contamination together with reduced cost of upkeep. The carbon steel carries the load and the alloy or metal lining affords protection to the contents and a lengthening of the life of the equipment.

According to the description cited above, special automatic machines join the backing plate and the sheet which forms the lining by means of full-strength resistance welds so spaced as to provide the bond and heat conductivity which the individual service conditions require. The joints in the lining are made with alloy weld rods which produce welds having characteristics similar to those of the lining itself. This construction is said to permit the use of very thin linings, assuring uniform thickness of the lining and full protection at all joints.

Completed tank for heat-treating strong aluminum alloys. Note methods of constructing and reinforcing the tank.

Furthermore it is pointed out that this construction allows for inspection of all the welds in the vessel walls by the customary X-ray and magnaflux methods. A procedure has also been developed for testing the spotwelded lining itself. This involves the introduction of pressure between the lining sheet and the carbon steel plate. Every weld spot is thus tested for proper fusion and tightness, yet the pressure is not sufficient to buckle the lining.

The accompanying illustrations show the tank in various stages of construction and also the finished tank loaded for shipment. They give an idea of the size of this equipment, also clearly showing the spotwelded lining. The approx. dimensions of the tank are: Length 18 ft., width 4 ft., depth 6½ ft.

Silicon Carbide Additions to Cast Iron

by JOHN A. BOYER

Research Dept. The Carborundum Co., Niagara Falls, N. Y.

In the January issue the first portion of this discussion was published. This is the concluding installment. There is a probability that in the near future this article will be followed by one or more other presentations which will record some of the practical results of the use of silicon carbide in actual foundry operations.—The Editors.

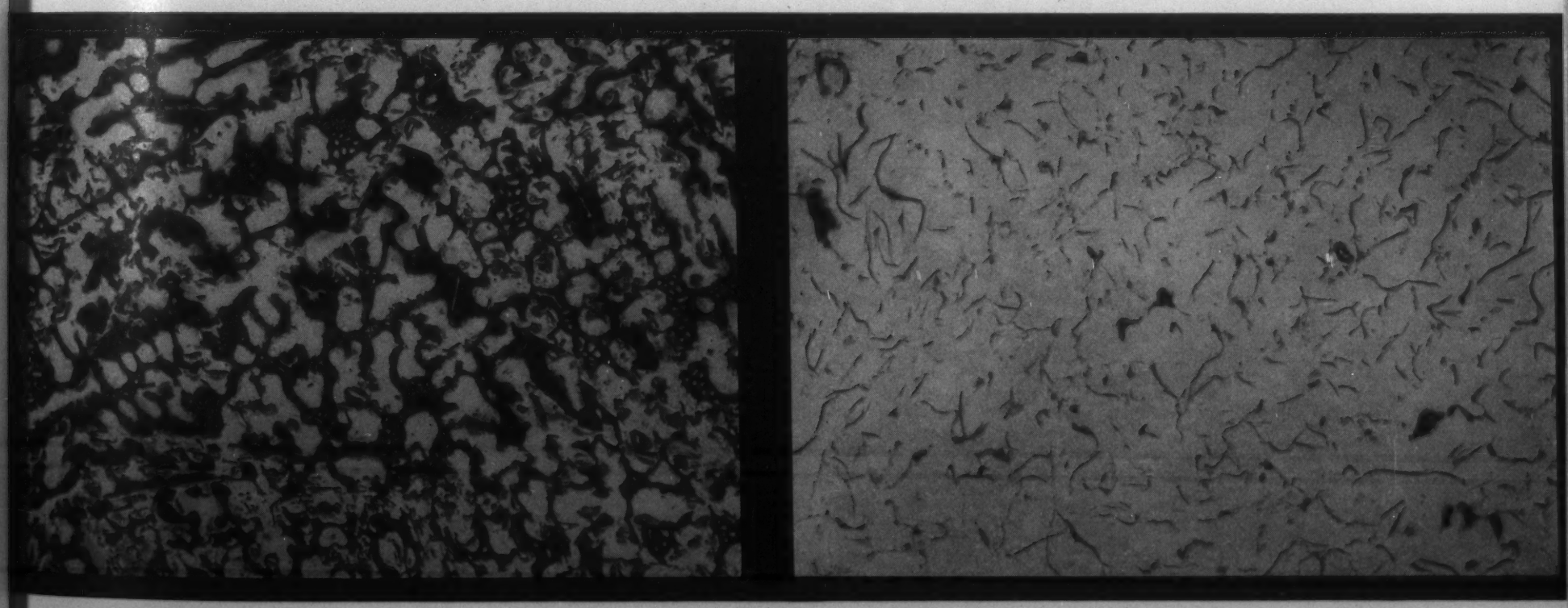
Breaking Up the Hard Constituents by SiC Additions

The rosette type of graphitization in a commercial gray iron, and the segregation of phosphide-rich areas at eutectic boundaries, are believed to be due to the presence of a considerable excess of eutectic after the primary dendrites have solidified. It is possible to suppress this eutectic by hardeners, or to produce an iron which, during solidification, shows no evidence whatever of a eutectic structure. In such an iron the dendrites interlock, and the interstices are separated by massive carbide rather than by areas of eutectic. This type of iron is characteristic of a high scrap charge, or of a charge which is so hard that it will not produce satisfactory gray iron castings without special treatment. With the addition of silicon carbide, the hard cellular network can be completely broken up, and fine-grained machinable castings can be produced in charges ranging from malleable scrap to charges quite high in phosphorus.

In re-melting malleable scrap the iron produced is usually a white iron having a structure similar to that shown in Fig. 13. Although there are a number of small eutectic areas, there are no isolated dendrites embedded in eutectic, but each dendrite lobe is almost completely surrounded by iron carbide. When 1 per

Fig. 13. Section of 1¼ in. Test Bar, Remelted Malleable Scrap. Alkaline sodium picrate etch. Si — 0.85, Mn — 0.52, P — 0.18, S — 0.112, T. C. — 2.90 per cent. Magnification, 100 X.

Fig. 14. Same Charge as Fig. 13; 1 per cent SiC Added. Alkaline sodium picrate etch. Si — 0.85, Mn — 0.52, P — 0.18, S — 0.112, T. C. — 2.90 per cent. Magnification, 100 X.



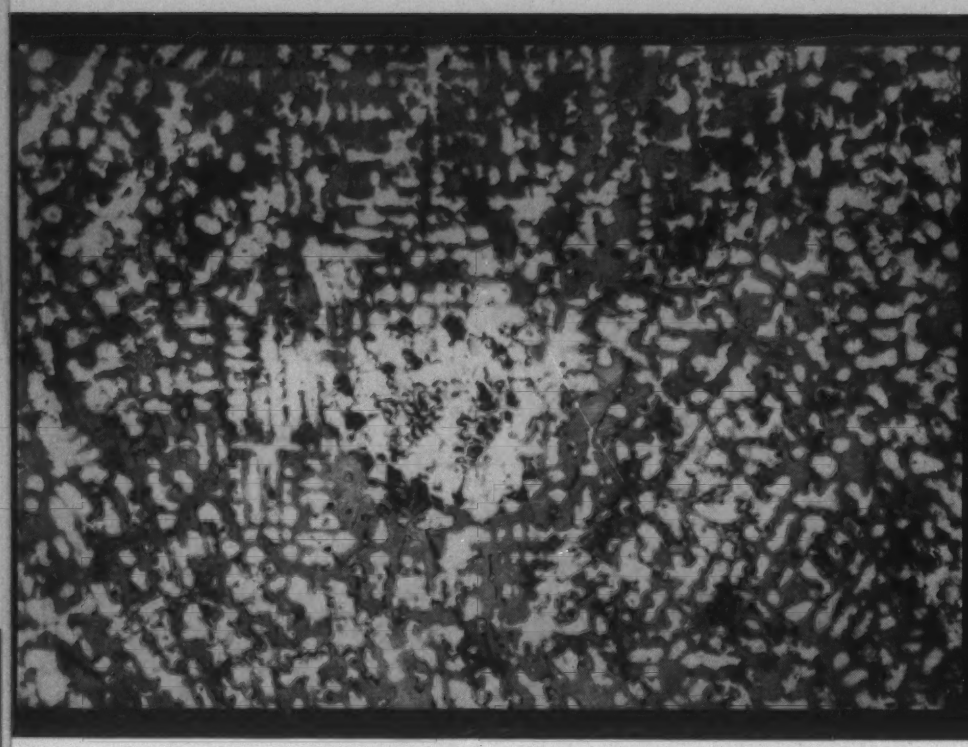


Fig. 15. Remelted 100 per cent Stove Plate Scrap. 1¼ in. section of telescopic casting. Alkaline sodium picrate etch. Carbide dark. Si — 0.87, Mn — 0.27, P — 0.57, S — 0.112, T. C. — 2.96 per cent. Magnification, 50 X.

Fig. 16. Four-in. Section of Telescopic Casting Shown in Fig. 15. Alkaline sodium picrate etch. Carbide half-tone, phosphide eutectic mottled. Si — 0.87, Mn — 0.27, P — 0.57, S — 0.112, T. C. — 2.96 per cent. Magnification, 100 X.

cent silicon carbide was added to the charge and the iron melted under identical conditions, the structure shown in Fig. 14 resulted. The specimen was entirely pearlitic except for the fine flakes of graphite. These flakes showed no growth in comparison with the interstices between the dendrite cells; the iron was readily machinable, and had a tensile strength of 41,000 lbs. per sq. in.

In making a high grade iron by adding silicon carbide to the charge, one would not recommend using 100 per cent stove plate scrap. It is possible, however, to produce an iron of fair quality by adding silicon carbide to such a charge, and the iron has a rather surprising machinability for this type of material. In using a charge composed entirely of stove plate scrap, it is possible to follow very gradually the changes that take place in converting a white iron of low eutectic content to a machinable gray iron. For this reason the micrographs shown in Figs. 1 and 15 to 22 have been chosen to illustrate the structural changes that take place during the graphitization of a hard iron, and also to show the effect of silicon carbide in breaking up the hard constituents.

In preparing the specimens, telescopic castings were used to provide different rates of cooling for the iron made from each charge. The first two charges made by remelting the stove plate scrap without the addition of silicon carbide were white or mottled, as they were poured at a comparatively low temperature. Typical microstructures of these charges are shown in Figs. 15 and 16. With further operation of the cupola the iron became gray, but was very difficult to machine. A typical microstructure is illustrated in Fig. 19. This specimen represented the best iron that could be produced in re-melting this type of charge.

In making the silicon carbide additions, the cupola was run from a cold start as before and 1½ per cent silicon carbide was added to each charge. The silicon carbide treated irons were gray irons having a fine graphitic structure and were readily machinable. Although operating conditions were unchanged, the metal and the slag were considerably hotter than in the previous runs made without the addition of silicon carbide.

Structures of the Cast Specimens

In Fig. 15 it will be noted that although the iron is a white iron, there is an almost complete absence of eutectic structure. Near the center of the micrograph there is an isolated rosette which has started to graphitize, but the remainder of the structure consists of a continuous network which for the most part is iron carbide.

Fig. 16 shows the microstructure of the 4-in. section of the same telescopic casting. The massive carbide surrounds the cells of the dendrites to form a fairly thin envelope, and there is no trace of any eutectic structure except in the mottled phosphide areas. It will be noted that these phosphide areas are well distributed between the interstices of the

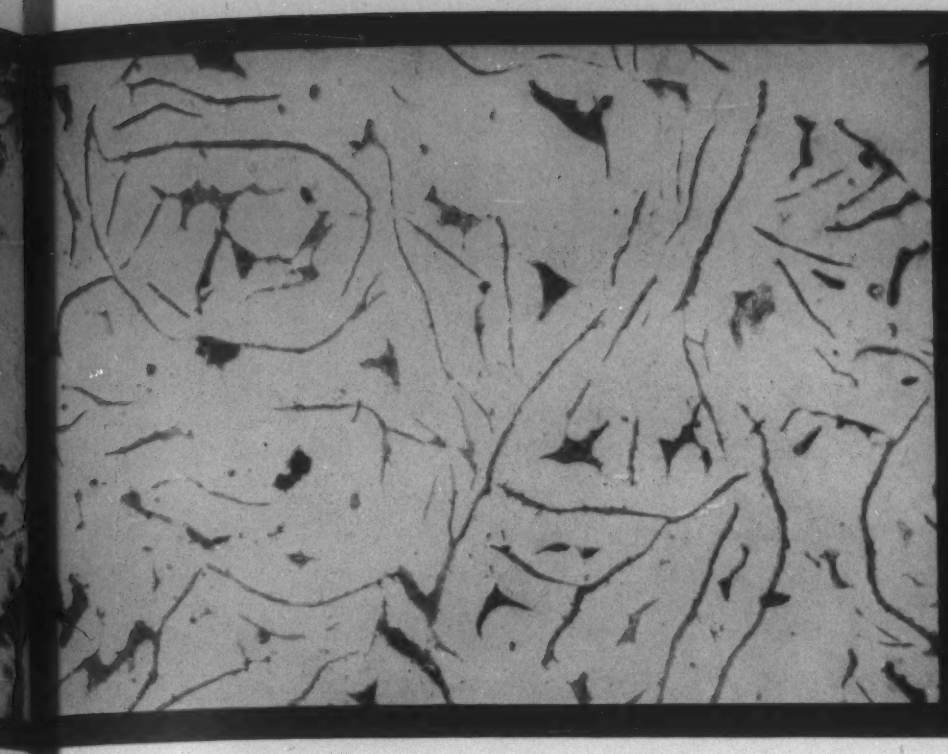


Fig. 17. Four-in. Section of Telescopic Casting; Charge same as Figs. 15 and 16, but Treated with 1½ per cent Silicon Carbide. Same etch as Fig. 2. Matrix pearlite (not etched). Cellular network completely broken up. Highly machinable. Si — 1.50, Mn — 0.31, P — 0.61, S — 0.108, T. C. — 3.30 per cent. Magnification, 100 X.

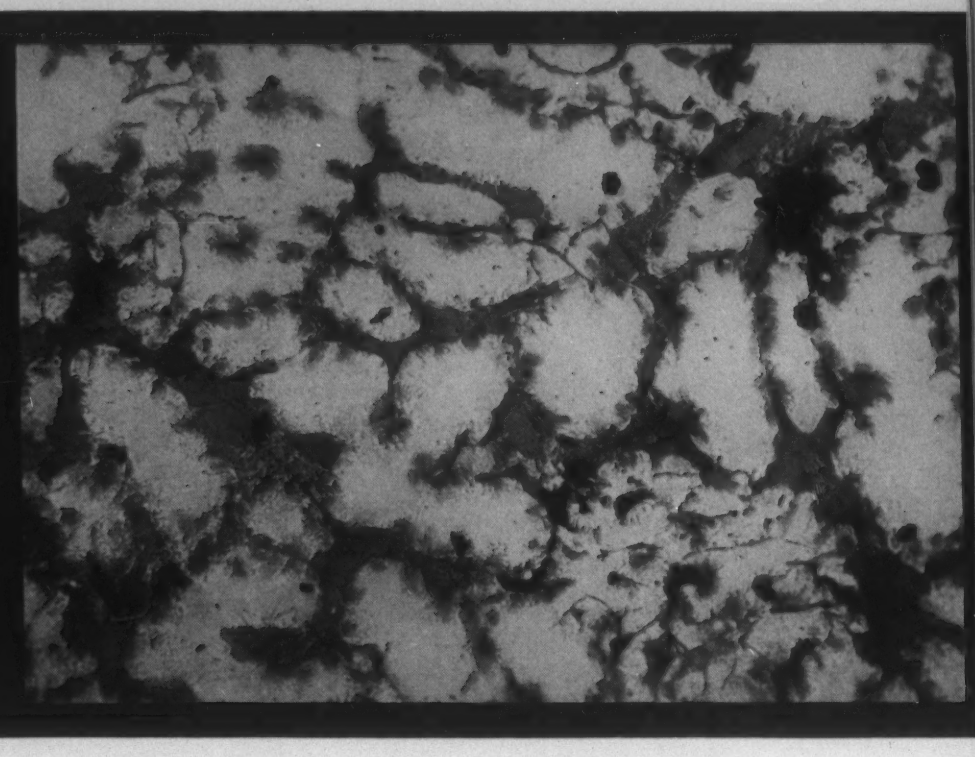


Fig. 18. Section from 2½-in. Telescopic Casting. Remelted 100 per cent stove plate scrap. Iron almost white but beginning to graphitize. Alkaline sodium picrate etch. Si — 0.87, Mn — 0.27, P — 0.57, S —0.112, T. C. — 2.96 per cent. Magnification, 100 X.

dendrites and are not segregated at the eutectic boundaries.

Fig. 17 shows the microstructure of a 4-in. section of an iron made from the same charge as was used in Fig. 16, but which was treated with 1½ per cent silicon carbide. The cellular structure is completely broken up, the graphite flakes are very fine for a heavy section and are comparable in size to the interstitial areas between the lobes of the dendrites, as shown in Fig. 16.

Figs. 18 and 19 show two successive pours from charges of the same composition, neither of which was treated with silicon carbide. The structure in Fig. 18 is that of a white iron, although some incipient graphitization has taken place. The fracture of the iron shown in Fig. 19 was gray, but the iron could be machined only with difficulty. It will be noted that there is a continuous network of hard constituents between the dendrite cells, and this network is similar both in quantity and distribution to the carbide shown in Fig. 18. In the gray iron, however, no massive carbide was present, and under higher magnification most of the network of hard constituents had the structure shown in Fig. 20. From the quantity and distribution of this carbide-phosphide complex and from the fact that it is surrounded by an almost continuous rim of carbide, which is not the case with the phosphide eutectic in a white iron, it would seem as though the structure resulted from the breaking down of the massive carbide. It is difficult to understand how such a process could take place, however, unless the carbide retained some phosphide in solid solution.

In the charges treated with silicon carbide, the phosphide-rich areas had the appearance shown in Fig. 21. It will be noticed that the carbide rim is entirely absent and the carbide content of the phos-

Fig. 19. Section from 2½-in. Telescopic Casting, Remelted 100 per cent Stove Plate Scrap. Iron gray; no massive carbide, but apparently an intermediate carbide-phosphide complex. Alkaline sodium picrate etch. Si — 1.19, Mn — 0.26, P — 0.58, S — 0.108, T. C. — 3.18 per cent. Magnification, 100 X.

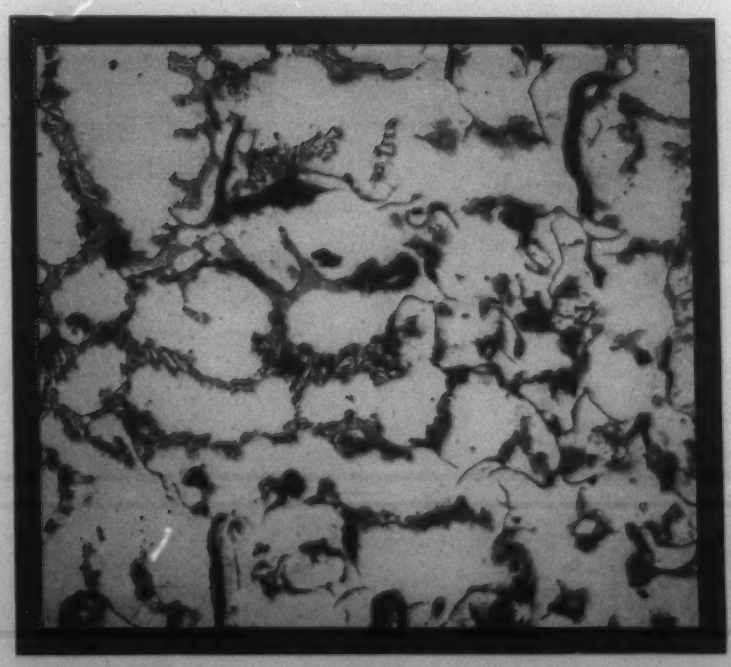


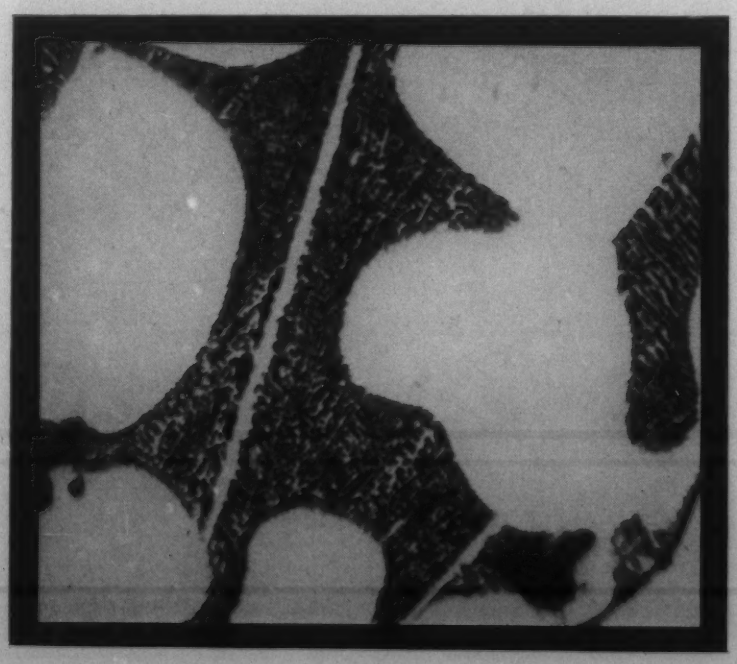
Fig. 20. Carbide-Phosphide Complex in Iron Made by Remelting 100 per cent Stove Plate Scrap. Carbide dark. Alkaline sodium picrate etch. Si — 1.19, Mn — 0.26, P — 0.58, S — 0.108, T. C. — 3.18 per cent. Magnification, 1000 X.

Fig. 21. Phosphide Area in Iron Made from the Same Charge as Fig. 23, but Treated with Silicon Carbide. Si — 1.50, Mn — 0.31, P — 0.61, S — 0.108, T. C. — 3.30 per cent. Magnification, 1000 X.

phide areas is considerably reduced from that shown in Fig. 20. The structure in Fig. 21 is very similar to that found in the normal phosphide eutectic of a white iron.

In order to show that the complex network in the untreated iron contained both phosphide and carbide, the specimen shown in Fig. 20 was repolished and etched for phosphide. The result is shown in Fig. 22.

Fig. 22. Area Similar to that Shown in Fig. 20, but Etched with Alkaline Potassium Ferricyanide. Phosphide dark. Si — 1.19, Mn — 0.26, P — 0.58, S — 0.108, T. C. — 3.18 per cent. Magnification, 500 X.



The breaking up of the network of hard constituents by the addition of silicon carbide is shown in Figs. 1 and 2. In the iron which was untreated, large areas were present in which the network was fairly continuous, whereas in the treated iron the network was well broken up. The matrix in all cases was pearlitic, and the silicon carbide treatment broke up the network of hard constituents without graphite growth or appreciable softening of the matrix.

Silicon Carbide Additions to High-Phosphorus Iron

As silicon carbide has been found to break up the phosphide-carbide network in ordinary gray iron, the material presumably would be effective in improving the properties of cast irons high in phosphorus. In a high-phosphorus cast iron, it is usually necessary to coarsen the graphite considerably to secure satisfactory machinability, and the coarsening of the graphite may readily result in a weakened structure and a type of porosity designated as "internal shrinkage," in which iron dendrites occur in what apparently are voids. The phenomenon has an appearance similar to the "piping" in a cast ingot.

By treating a high-phosphorus iron with silicon carbide it is possible to take advantage of the hardening and increased wear-resisting properties of the higher phosphorus content and to secure satisfactory machinability by breaking up the phosphide carbide network by means other than decidedly coarsening the graphite. As an additional hardener steel scrap

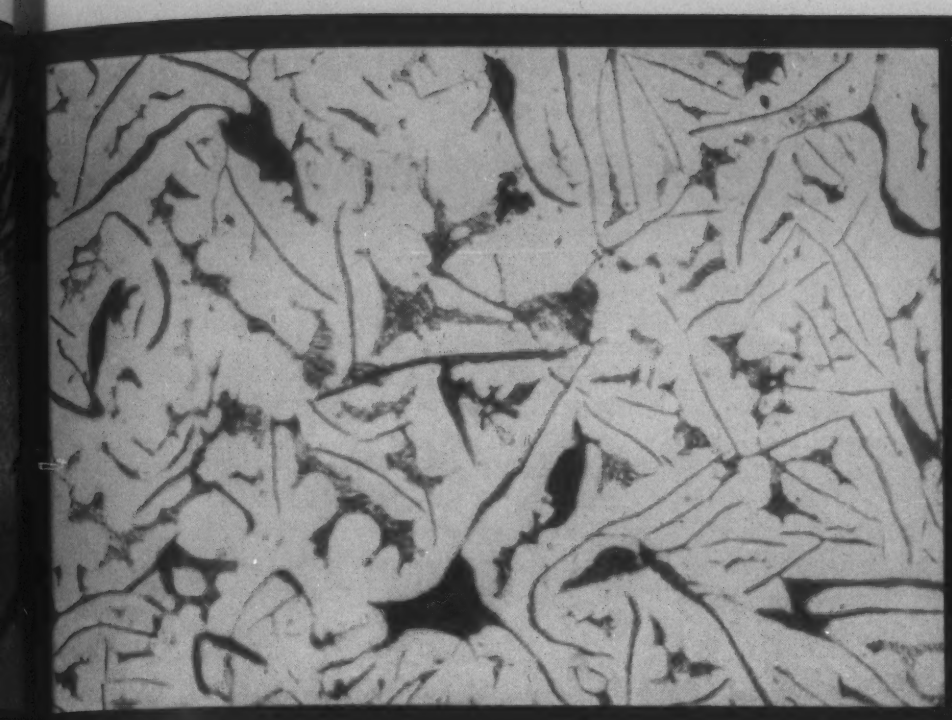


Fig. 23. High-Phosphorus Iron, Containing 0.8 per cent Phosphorus, Made under Ordinary Conditions —2½ in. Section. Alkaline sodium picrate etch. Si — 1.79, P — 0.77, S — 0.077, T. C. — 3.62 per cent. Magnification, 100 X.

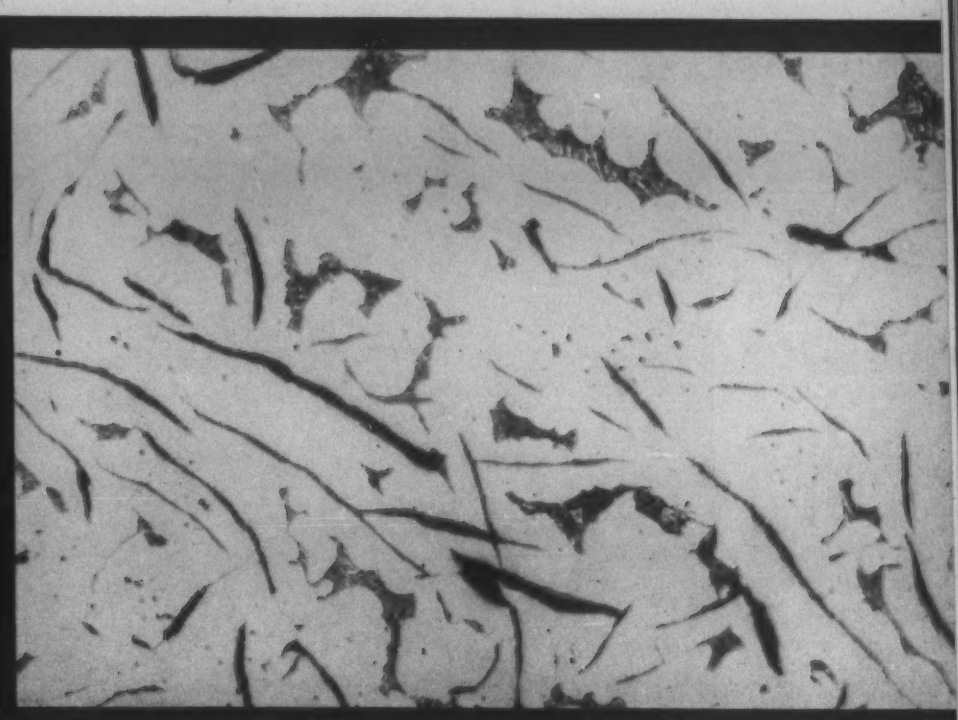


Fig. 24. Iron with the Same Phosphorus Content but Made from a Harder Charge. Treated with silicon carbide. 2½-in. section. Alkaline sodium picrate etch. Si — 1.85, P — 0.84, S — 0.09, T. C. — 3.45 per cent. Magnification, 100 X.

may be added to the high phosphorus pig or scrap. The microstructures of comparable sections, one with the usual type of charge and the other with a harder charge treated with silicon carbide, are shown in Figs. 23 and 24. The tensile strength, deflection and hardness are increased without sacrificing machinability, and the "porosity" of the iron can be minimized by the use of a harder charge.

Conclusion

The micrographs presented in connection with the effect of silicon carbide on cast iron are not intended to represent any planned research investigation. The nature of the reaction with silicon carbide necessitates large scale operation and slagging conditions that cannot be obtained with laboratory melting. It is impossible to take over cupolas in a large foundry working at high production without using charges that are reasonably certain of producing good castings.

The work in connection with stove plate scrap was done at a local foundry at Niagara Falls in a small cupola. The changes produced are somewhat exaggerated by the poor quality of the original charge. but they have afforded a considerable amount of metallographic information.

It is not intended to give the impression that silicon carbide is a "cure-all" for cast iron. The structures obtained in many instances can be obtained by other methods. The mechanism of the reaction is more or less uncertain, especially in view of the work of Boyles on the effect of hydrogen and oxygen on cast iron. The tests, however, have involved considerably more than 100,000 tons of cast iron, and have shown that a hard, close-grained machinable iron can be obtained from a comparatively low-grade charge through the addition of silicon carbide.

Throughout this investigation the silicon carbide employed was in briquetted form, sold commercially under the trade-name "Ferrocarbo" by The Carborundum Company, Perth Amboy, N. J. Since the essential constituent of these briquettes is silicon carbide, the term silicon carbide has been used throughout this article.

[1] Brown, William A.—U. S. Patent No. 2,020,171—Addition of Silicon Carbide to Cast Iron.

[2] Boyles, Alfred—"The Freezing of Cast Iron." *Trans. Amer. Inst. Mining Met. Engrs.*, Vol. 125, 1937, pp. 141-203.

[3] LeChatelier—"Photomicrographs of Iron and Steel," by Everett L. Reed, page 220. (John Wiley & Sons, New York, 1929.)

[4] Murakami—"Photomicrographs of Iron and Steel," by Everett L. Reed, page 221. (John Wiley & Sons, New York, 1929.)

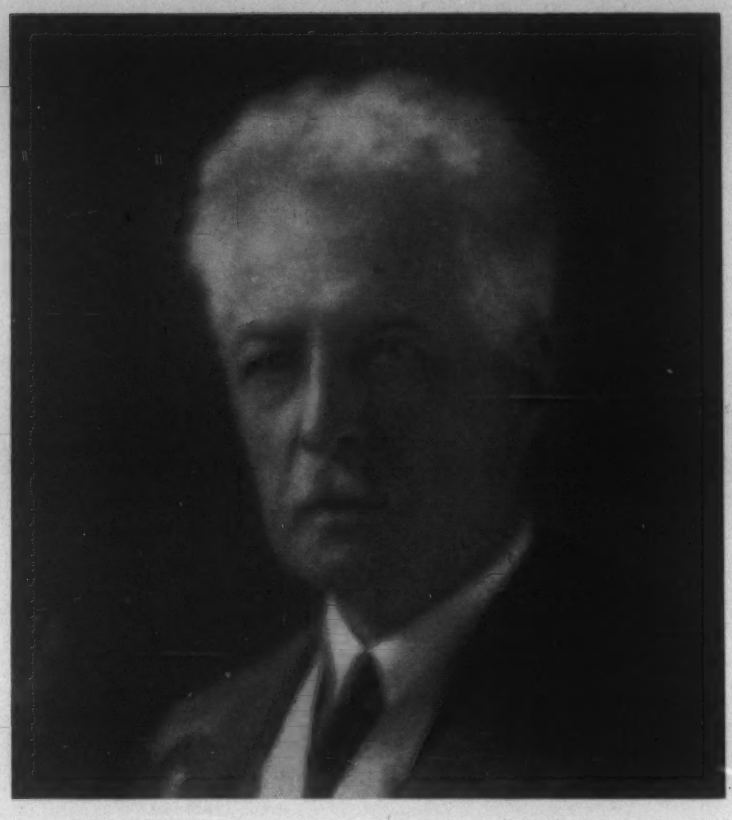
Scrap Iron and Steel

To the Editor: I greatly welcomed the appearance of the "Scrap Iron and Steel" editorial in your October issue. especially its last paragraph.

It is quite time that metallurgists and engineers, as well as social and political "scientists," took some notice of the social and political implications of their profession, otherwise their knowledge and skill is more likely to be blindly used to help push the world back to barbarism than forward to peace and civilization.

CHAS. F. RAMSEYER.

7850 So. Shore Drive, Chicago.



Albert Sauveur

1863-1939

It is difficult to believe that the grand old master of American metallurgy has departed this life, never to return. For those of us who have known him for so many years, who have become so accustomed to his presence and have admired him, who have fallen under the influence of his clear mind and charming person, and have come to identify him with the profession of metallurgy—many of us former students—this is an inconceivably sad fact that leaves the future poor.

The great men of metallurgy who fought the early fight for a struggling new science a generation ago are now mostly gone—Stead, Arnold, Martens, Tammann, Sorby, Osmond, Roberts-Austen, Howe. Those early days were great days, great men trod the boards of the lecture platform—men no less great than those of the other sciences. Sauveur was one of them, who stayed with us much longer than the rest. Most of metallurgy as we now know it was developed during his lifetime. He threw himself as a young man into the midst of those early discussions on the hardening of steel, and he remained an active, never a passive, protagonist even until the last week. He drove industry to recognize metallography, he steadily insisted on the need for scientific research, in his latter days he encouraged the application of new methods even though he himself did not partake and even though he recognized the extremes of current fashion in research, and above all he brought to bear the influence of his charming and forceful person upon the young men of his profession.

He was very proud indeed of his former students; he spoke and wrote often with a fine pride of the positions they had reached, and of the influence they had come to exert in the profession he loved so well. He loved them, and he loved all people; he always knew that all things that move people to do and to accomplish come from the few who inspire, unusual men who exert an influence far beyond that of the average, and knowing this he exalted those of whom he approved and those whom he loved.

And thus he lived and fulfilled his own ideals, spreading his influence to his students and many thousands who had never sat in his class rooms. He was the master and all the rest were his students; he was the true professor whom others can hope only to emulate. There must be desolation in the legion of his followers, a desolation that shall not soon lessen and that only new life can assuage.

ROBERT F. MEHL.

Professor Sauveur's life bridged a period in which American metallography rose from nothing to its present position as an indispensable, if not the most indispensable, tool of the metallurgist. In this rise Professor Sauveur played a major part. He has most interestingly and most modestly sketched his early days in his "Metallurgical Reminiscences." Today many thousands of metallographic examinations are made as necessary routine in the production of alloys and structures far more serviceable than would ever have been possible to produce without this tool which Professor Sauveur had so great a part in shaping. The era of introduction has long since passed into the era of use.

The part Sauveur played in research on metallography would be enough to win lasting fame for any man. But he not only developed the tool, he used it, with other tools, to find and clarify metallurgical principles. The title conferred upon him by common consent was not "Dean of American Metallographers," it was "Dean of American Metallurgists." His text books, his articles, and the inspiration he gave to his students, both at Harvard and in his correspondence courses, would stamp him as a great educator even had he not done so much personal and pioneering research. One of the clearest discussions of the malleableizing process is due to Sauveur and his interests covered the whole field of metallurgy. His activity did not cease with his retirement from teaching; it was maintained to the very last. The November and December 1938 issues of METALS AND ALLOYS carried his discussion of the microscopical constituents of steel, and his translation of a French discussion on rimming steel.

He had a full life. Honors were heaped upon him, which he bore most modestly, accepting them as tokens of the service performed by metallurgy to science and industry rather than as tokens of his own worth.

Sauveur had no enemies. He had an amazing number of friends because he was unassuming and friendly himself. The youngest cub could approach Sauveur with even a foolish question, and be put straight, not merely in a courteous manner but with genuine interest in the cub and in whatever was bothering him. Hundreds of people who may only have talked to him for a few minutes have a deep appreciation of his kindliness and count him their friend.

We mourn a great man, and a great gentleman.

H. W. GILLETT.

Editorial

(Continued from page 33)

a compound. When the metal predominates, as is usually the case, we have no hesitation in calling the mass an alloy—pearlitic steel will naturally be defined as an alloy of Fe and Fe_3C—but when we have 85 per cent or more of a carbide such as that of W, and 15 per cent or less of Co or some other bonding metal, what have we then? There is doubtless enough solubility of the carbide in the metal to make the matrix an alloy, so it's a matter of choice how we designate the mass. Actually we speak of "carbide tools" since the carbide predominates, without thereby denying the alloy character of the matrix. Such cases are something like deciding when a penny that a youngster has put on the street car track ceases to be a penny. The slot machine won't give down gum when the coin is too battered, but the drug store may still accept it for an all-day sucker. It's a penny or a metal mass depending on environment. There we go with another use of "metal" when the thing is really an alloy, and for precision we might have said "metallic mass." But such a term as "Monel metal" doesn't lead to real ambiguity. Indeed we're thankful that it wasn't called "Monelloy."

The solubility question comes up in regard to additions to steel for grain size control. A tiny addition of Al, Ti, or V is thought to produce, at some time in the cooling of the melt or the solid, a submicroscopic cloud of some compound, ordinarily postulated as Al_2O_3 in the case of Al, and possibly a vanadium carbide in the case of V. By analogy with other experiences, we think of Al_2O_3 as essentially insoluble, but feel that a metallic carbide may well be soluble in steel. A very definite solid solubility of sulphides and a very limited solubility of silicates are pretty well accepted by students of inclusions. Since the grain size controlled steels do show grain growth at a sufficiently elevated temperature, one can hardly deny the possibility that at such temperature the submicroscopic Al_2O_3 might go into solution. When the Al is higher than suffices to bind the O and N, and perhaps the S, as Al_2O_3, AlN, and some Al sulphide, we tend to think of the excess second increment as the alloying one, and tend not to term the first increment as alloying, probably because, subconsciously, we feel that that initial increment first forms a compound. Yet this compound may alloy as truly as does Fe_3C into which C, diffusing through ferrite, would logically combine. Hence a grain size controlled steel might be an Fe-C-O-Al alloy as truly as it is an Fe-C alloy.

The dividing line between "carbon" and "alloy" steel is of course one of economics and of the price structure, rather than a metallurgical boundary. One is accustomed to differentiate between ordinary killed carbon steel and a steel with, say Mn or Si, raised from the ordinary level to an "alloying level" at which enhanced mechanical properties and not mere soundness, are sought. This subsidiary differentiation certainly doesn't keep ordinary carbon steel from being an alloy, in which Mn and Si as well as C are alloying elements. Part of the mechanical properties are due to Mn and Si. Can we deny them credit for alloying action?

In other phraseology the intention comes in: We may get a 0.20 per cent Cu copper-bearing steel from residual Cu in scrap without intentionally making an alloying addition. Like the rose, however named, the 0.20 per cent Cu, from whatever source, produces an alloy steel resistant to atmosphere corrosion. Several "low alloy, high strength" steels contain only ten points or so of an essential element, and when that little exerts a definite effect we can't deny it the appellation of alloying element.

What content of impurity shifts a metal from the metal to the alloy class is a matter of the context. Prime Western zinc is, by intent, a metal, and 99.95 per cent Zn would be, by analogy and by earlier standards, a very pure metal. To the die-caster, however, such zinc has alloying contaminants and he is likely to think of zinc metal as 99.99 per cent Zn.

In the Alloys of Iron Monograph Series, Cleaves & Thompson started out to write about pure iron, but found that the contents of such a book would consist of the title and the words "There isn't any." So they discussed "The Metal, Iron" and include data on samples with as much as 0.1 per cent of reported impurities. Yet precipitation hardening effects in ferrite are noted at so low a C content that the whole solubility curve is compressed between about 0.005 and 0.035 per cent C. All diffusion of C in ferrite must depend on this solubility, so 99.99 per cent Fe, 0.01 per cent C would certainly be an Fe-C alloy, despite our regular use of "Ingot Iron" for a less pure metal.

For a really true definition, we can state that a metal or an alloy is whatever we think it is when we use the term.

Both as to metals and alloys, there will be cases where everyone will so term them, other cases where no one will apply those terms, and border line cases where proper terminology is uncertain. But this is no unusual condition. The ethnologists use the term "anthropoid" just as the chemist uses "metalloid." The man in the street will think of he-men, men, sissies, morons, idiots, administration yes-men, and apes. His definition of a man will depend largely on the context, i.e. whether that context requires that emphasis be laid on physical, mental, or moral attributes. From a strict point of view, the small, or even infinitesimal impurities present in commercial metals almost invariably exert an alloying effect, and when we are thinking of this fact, the material is an alloy. When we are not examining the situation so

(Continued on page 66)

closely, the material is a metal, and the context tells which point of view is utilized, so that it is infrequent indeed that wordy explanation is required.

Hence we finally conclude that it is unwise to ask for too rigid a definition of a metal or an alloy. A reasonable looseness that will admit or exclude the border line cases according to the context seems desirable.

These are words that everybody owns, they don't belong exclusively to the technologist like some others around which recent discussion has raged. So whatever different meanings they have to people in general, *are* their meanings, whether precise definitions may or may not be ascertainable.

It may be as interesting to the reader, as it has been to us, to examine his own definitions of these words which we all use so glibly, and often without the qualifying adjectives that would be needed were we seeking academic and lexicographic precision. We hope that some of the readers who have ideas on these matters will jot them down in "Letters to the Editor." —H. W. G.

Welding Low-Alloy Steels

In considering the whole subject of avoidance of weld-hardening in low alloy, high strength steels, two expedients that are in use in this country, but not mentioned by Swinden and Reeve, deserve mention. Since phosphorus does not produce quench-hardening, but is an extremely potent ferrite-strengthener, steels with low carbon and high phosphorus, plus a variety of other elements, are popular here, though English metallurgists have scarcely utilized them as yet.

The use of vanadium in steels whose carbon and manganese content would otherwise make them unsuitable for welding is a well known expedient, the mechanism for which is probably very similar to that ascribed to Ti on pages 48 to 51.—H. W. G.

A LETTER TO THE EDITOR

Some Unexpected Properties of 18 and 8

To the Editor: In our studies of the effects of various gas environments in manufacture on the properties of stainless steels, unexpected properties of several melts came to our attention which appear of sufficient importance to report at this time. For example in the preparation of 18-8 alloys in high vacua, we found that ferrite appeared in the furnace-cooled ingots as well as in the same heats forged, then annealed at 1150 deg. C. for 1 hr. and 20 min. and water quenched. According to previous experiments recorded in the literature, it is indicated that low carbon 18-8 quenched from temperatures of this order should be entirely austenitic and non-magnetic. In one of our melts analyzing 14.87 per cent chromium, 8.47 per cent nickel, and 0.011 per cent carbon quenched from 1150 deg. C., we found approximately 100 per cent ferrite and correspondingly strong ferromagnetism.

The melts were produced in a vacuum induction furnace of ½-lb. capacity using either alundum or beryllia crucibles. Electrolytically prepared iron, chromium and nickel were used for some melts to insure maximum purity and minimum contamination by nitrogen. Other melts were prepared using Armco iron and commercial ferrochrome. The melts were prepared either in vacua (10^{-4} mm.) or in purified gas atmospheres of hydrogen or nitrogen. The lattice structure of the alloys was obtained by X-ray analysis.

Preliminary results on several check runs indicate that vacuum melted and cooled low carbon 18-8 alloys, starting with electrolytic materials or ferrochrome will, under conditions which prevent gas contamination, always contain ferrite as well as austenite and may consist practically wholly of ferrite. This is true of the furnace-cooled ingots and the air-annealed forgings. The 18-8 alloys melted in hydrogen are also ferritic, differing in this respect in no appreciable degree from the vacuum melted alloys. Employing a nitrogen atmosphere, the alloys are practically all austenitic which is in agreement with commercial experience. Whereas the vacuum and hydrogen melted alloys are free of nitrogen, the nitrogen melted alloys contain from 0.15 to 0.30 per cent nitrogen. It appears that the phase diagram for low carbon 18-8 containing nitrogen is not adequate to explain the behavior of nitrogen-free alloys.

Hardness tests on specimens which were first forged and then annealed at 1150 deg. C. show that ferritic 18-8 obtained in this way has a Brinell hardness of 228, whereas austenitic 18-8 has a Brinell hardness of 165. Corrosion studies using ferric chloride in a specially designed corrosion tester indicate that the ferritic vacuum and hydrogen melted alloys are corrosion resistant, comparing in their resistance with commercial 18-8 steels. The austenitic nitrogen melted alloys are found to be best in corrosion resistance.

Heating any of these alloys for a brief period at 600 deg. C. decreased markedly their corrosion resistance. During the same heat treatment the hardness of the alloys increased, in some cases going through maxima and minima. The increase in corrosion and hardness occurred despite the low carbon content (for some melts 0.006%) which has led to an interpretation for this behavior in chrome-nickel-iron alloys independent of carbon. Details of experiment and theory will be published later, at the completion of additional experimental work now in progress.

This work was begun under the auspices of The Chemical Foundation and supervised by the Corrosion Committee at M.I.T. of which Prof. R. S. Williams of the department of metallurgy is chairman. Research is projected for the continued study of nitrogen-free chrome-nickel steels as well as the influence on pitting behavior of various minor constituents normally present in commercial melts. The latter study includes in addition to the factors accounted for by gas environments during production, the effect of various refractories used to contain the melts.

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